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Volume 6/Numb

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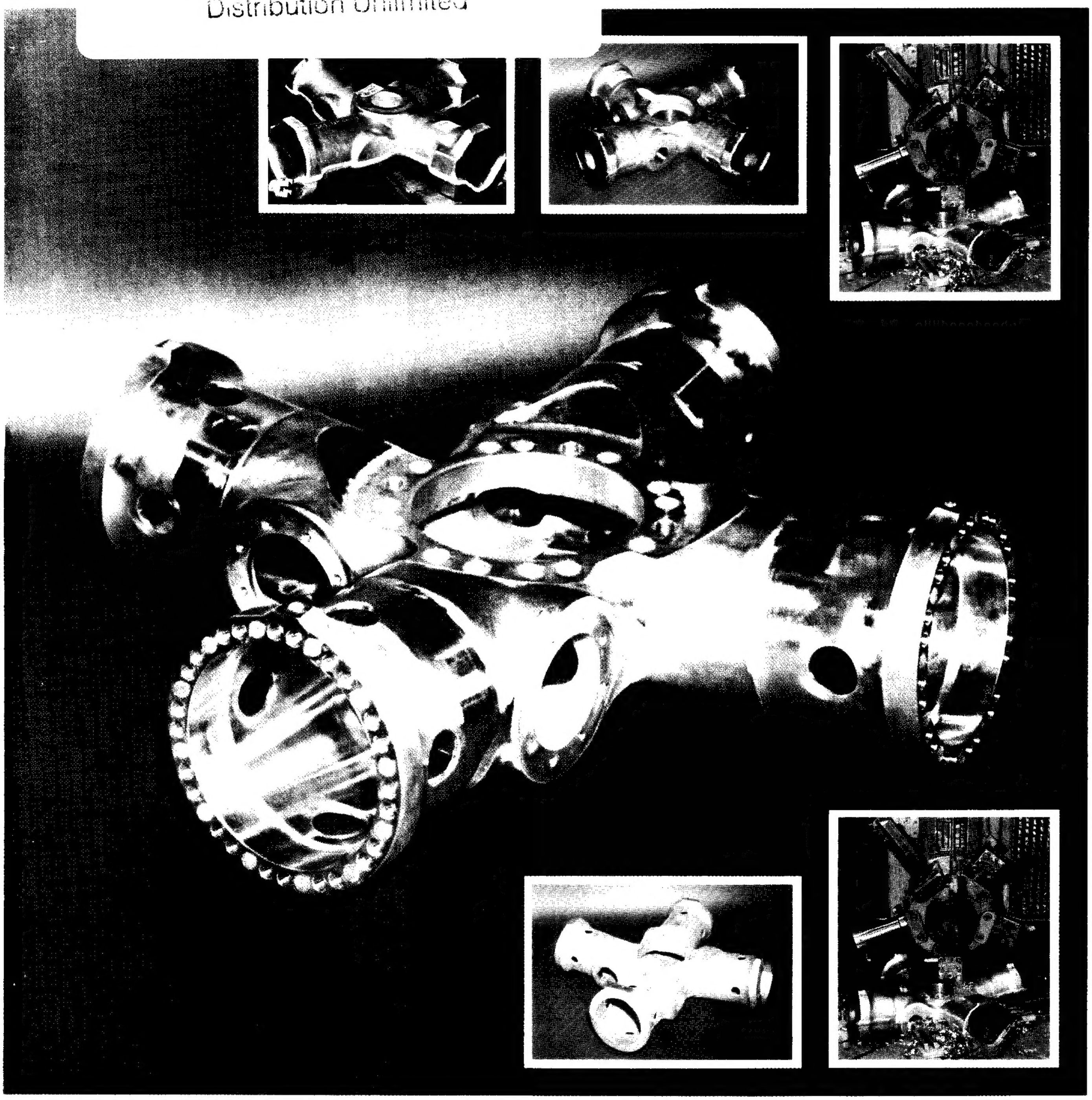

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Contents

1 Comments by the Editor

3 Implementation of AVRADCOM MM&T

7 RF Curing of Epoxy Composites

14 Composite Main Rotor Tubular Braided

17 Organic Materials Lab in Forefront

23 Brief Status Reports

28 TACOM II Conference A Success

30 Manufacturing/Productivity Lab Innovative At MIT

34 MIT Materials Processing Center Diverse

40 Isothermal Forging of Engine Parts

46 Index by Topic

About the Cover

A cast titanium main rotor hub for the Army's BLACK HAWK helicopter will save 88% of the material wasted by machining a titanium forging. The present method of machining forged components (top) uses a 1000 lb solid forging which is machined to a finished part weighing 150 lb. The cast method (bottom) uses a 250 lb shell casting which is machined to the finished 150 lb component. The Ti-6Al-4V casting is hot isostatically pressed, beta heat treated, and overaged in order to attain physical properties suitable for its intended use. Cost of production is 15% less than with forged components. Sikorsky Aircraft Division of United Technologies Corporation has achieved this capability under a program sponsored by the U.S. Army Aviation Research and Development Command.

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Comments by the Editor

RAYMOND L. FARROW

The year will be compressed into the last six months of 1981 for the U. S. Army ManTech Journal as the magazine completes its fifth full year of publication, meanwhile changing its format and style as mentioned in the last 1980 issue. The new format can be seen in some of the articles and other features within the covers of this issue. As with most transitions, the new format and style will be gradual, being implemented as new material is acquired more specifically suited for the new look. Again, as we asked our readers in the last issue of 1980, we would welcome any constructive commentary pertaining to how we can best present material for the general elucidation of our audience. Please address your remarks to the attention of the Editor at the U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172.

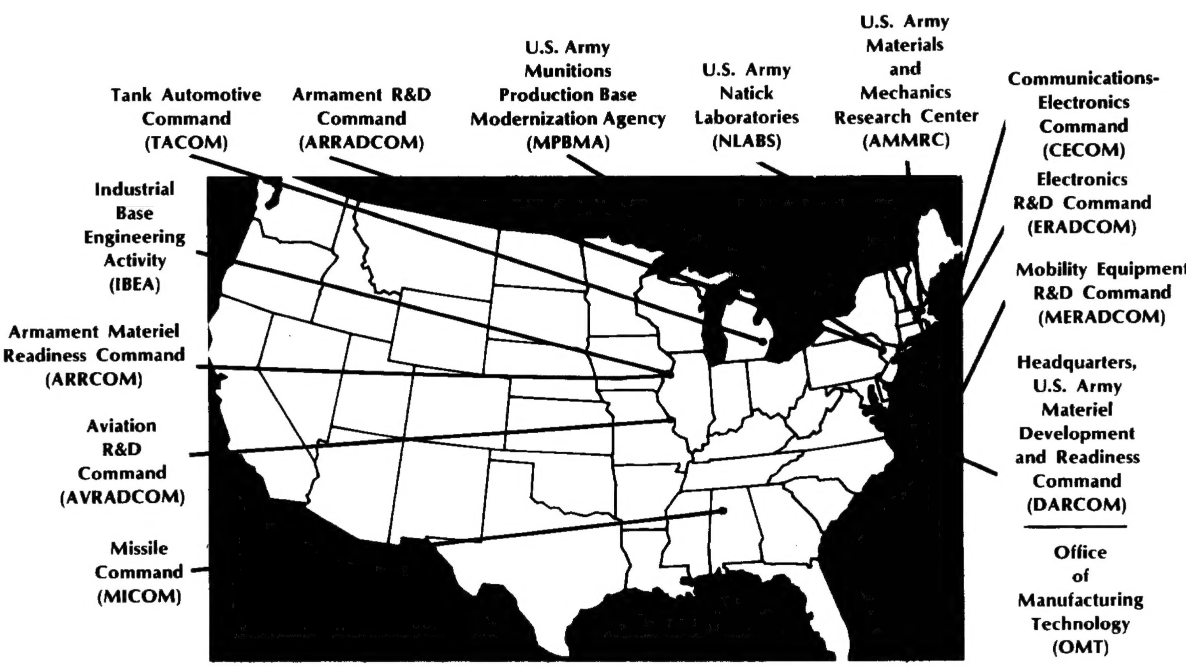
The U. S. Army Tank Automotive Command is to be commended on the fine manufacturing technology conference on military vehicles it conducted 28 June-1 July of this year. AMMRC staff were pleased to have been so actively involved in the presentation of so important a conference. MT Conference II was attended by over two hundred fifty managers and engineers involved with man-tech programs within the military and industry representing over seventy companies. Five individual panels—Transmission, Engines, Track and Suspension, Tactical Vehicles, and Hull and Turret—met simultaneously to consider concepts proposed by attendees totalling about two hundred potential projects. Over one hundred eighty presentations were given during the three day conference, results of which will be detailed in a ManTech Journal article later in the fall. The new directions being taken in noncontact gaging and sophisticated metrology will produce significant changes in tank production. The application of lasers for measurement of tank hulls already has demonstrated dramatic savings in time and labor and will continue to impact heavily on some of the most important production bottlenecks encountered in producing our armored vehicles. Expected to play dominant roles in future TACOM MT projects are computer directed numerical controls, laser metalworking, intellectual machine robotics, and sophisticated welding systems, particularly for aluminum armor. The conference was the first such effort since AMMRC assisted TACOM in their first man-tech conference in 1976 and marks a successful period following that conference. This one also will be highly productive of well conceived new projects, and we look forward to being involved in more endeavors like these in future years.

The staff is planning to complete all four issues for 1981 by the end of this year, meaning that the frequency of publication during the rest of 1981 will be doubled. The accomplishment of this goal will enable us to begin the 1982 publication year right on schedule and then to publish normally by quarters the rest of the coming year.

One of the new features carried in this issue is illustrated by the pair of articles on academic manufacturing technology activities — in this case, the Laboratory for Manufacturing and Productivity and the Materials Processing Center at MIT. These features are based on papers presented at the 1980 MTAG meeting; forthcoming issues of the ManTech Journal will feature one or more similar programs under way at top engineering schools around the United States. Also a special feature in this issue is an article reviewing the accomplishments and outstanding capabilities of the Army's Organic Materials Laboratory at Watertown, Massachusetts. The ManTech Journal staff covered the story of this facility at the recommendation of AVRADCOM personnel, who consider the OML to be one of the most outstanding of such laboratories — one which remains right in the forefront of its area of technology and which proffers enormous service to the Army commodity commands.

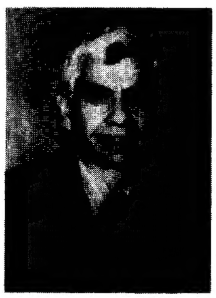
Other features to be noted are, predictably, the result of some of the Journal's Advisory Committee's recommendations. An example is the section on brief status reports. Another feature is that typified by the commentary on the TACOM Manufacturing Technology Conference II held in July. Also, readers please note the request for additional information card in the tearout section inside the back cover. We hope also to add a section on "Letters to the Editor" in the next upcoming issue. Again, send us your comments so we can publish your ideas.

DARCOM Manufacturing Methods and Technology Community



Part of Overall Project Planning

Implementation of AVRADCOM MM&T



GERALD A. GORLINE is a graduate Industrial Engineer with BSIE (1959) and MSIE (1966) degrees from Washington University, St. Louis. He currently is assigned as Manager of the AVRADCOM Productivity Improvement Program. He has been responsible for managing the AVSCOM and AVRADCOM Manufacturing Technology Program during the past fourteen years. In addition, he has served as project engineer for the development of advanced manufacturing technology projects for CAD/CAM and engine and aircraft components used in Army helicopters. He has twenty-two years of manufacturing engineering experience, of which nineteen are in the aerospace industry involving both fixed wing and rotary wing manufacturing areas with aerospace firms and with the U.S. Army. He is active with the Aerospace Division, American Institute of Industrial Engineers, and the American Helicopter Society. He also is a member of the Metals Committee of the Tri-Service Manufacturing Technology Advisory Group (MTAG).

In keeping with DOD's increased emphasis on implementing the results of manufacturing methods and technology (MM&T) programs, the Army Aviation Research and Development Command's (AVRADCOM) MM&T efforts are aimed at insuring the use of new technology on defense production lines. DOD's MM&T thrust is directed toward developing or improving manufacturing processes, techniques, materials, and equipment for producing defense systems in a timely, reliable, and economical manner. To meet this objective, it is imperative that the resulting technologies be incorporated into production of major systems — helicopters, tanks, missiles. Thus, DOD commands can no longer support projects solely to advance technology — implementation must be planned from the outset.

AVRADCOM adheres to this policy and is committed to seeing MM&T results on the production lines rather than lost in the files or gathering dust on library shelves.

To accomplish this, the responsibility for administering MM&T programs within AVRADCOM lies with the Production Technology Branch of the Directorate for Systems Engineering and Development.

Implementation Built In

As soon as AVRADCOM recognized the need for implementation in the mid 70's, the MM&T program manager took positive steps to build it into all efforts. This meant that implementation became an important part of initial contractual efforts, not an afterthought following technology development. Such an approach was initiated informally in FY 75 on a project to develop manufacturing technology for the cast titanium impeller of an auxiliary power unit. The potential contractor was asked to furnish, at project inception, information regarding efforts directed toward full qualification of the item on a future production line. The contractor identified a 200-hour engine qualification test and agreed to perform this test without cost to the government. The program is now in the final stages and the early implementation effort has proved worthwhile.

Based on such early efforts, the AVRADCOM MM&T program manager issued implementation instructions and

NOTE: This manufacturing technology contracting procedure is being implemented by the U.S. Army Aviation Research and Development Command under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The AVRADCOM Point of Contact is Mr. Gerald Gorline, (314) 263-1625.

procedures to project engineers in 1977. These were that the procurement solicitation will request an implementation plan from the contractors and a letter endorsed by a high company official that the manufacturing technology will be used on their production lines. The implementation plan will depict and identify all efforts, equipment, and costs over and above the MM&T effort to get this technology incorporated into production. These instructions have since been formalized. While such directives are issued to emphasize the importance of establishing implementation procedures, AVRADCOM recognizes that there is no universal, straightforward procedure. Each MM&T program presents its own individual set of problems and circumstances. Often, the project engineer must apply creative and innovative techniques to achieve AVRADCOM's implementation objective.

Implementation Plan Derived

Nonetheless, a general implementation procedure has evolved through application of these directives and AVRADCOM's experience in administering projects. A flow chart of this procedure is shown in Figure 1. When a project is formulated, the project engineer begins immediately to look for an application. As the program takes root and is accepted following review by AVRADCOM, DARCOM, the Department of the Army, and DOD, a more definite implementation plan is outlined. This plan involves the airframe or engine manufacturers and affirms their intent to use the proposed manufacturing technology in actual production. This industry commitment is usually formal, depending on the nature of the MM&T effort.

When the project has been funded, potential contractors are asked to submit a preliminary implementation plan as part of their proposal. These plans identify all testing procedures, equipment, and tools required to introduce the technology to production, beyond those needed for the MM&T effort itself. They also include a written intent to use the technology, signed by a high ranking official.

The plan is submitted to the program/product manager, who must concur on the use of the technology. The Director of Development and Qualification must approve the implementation plan when qualifications and equipment are involved. Where funds beyond those needed for the MM&T effort are required, the program/product manager must provide them. In addition, personnel of the Directorate for Development and Qualification are required to review and approve the adequacy of the contractor's flight

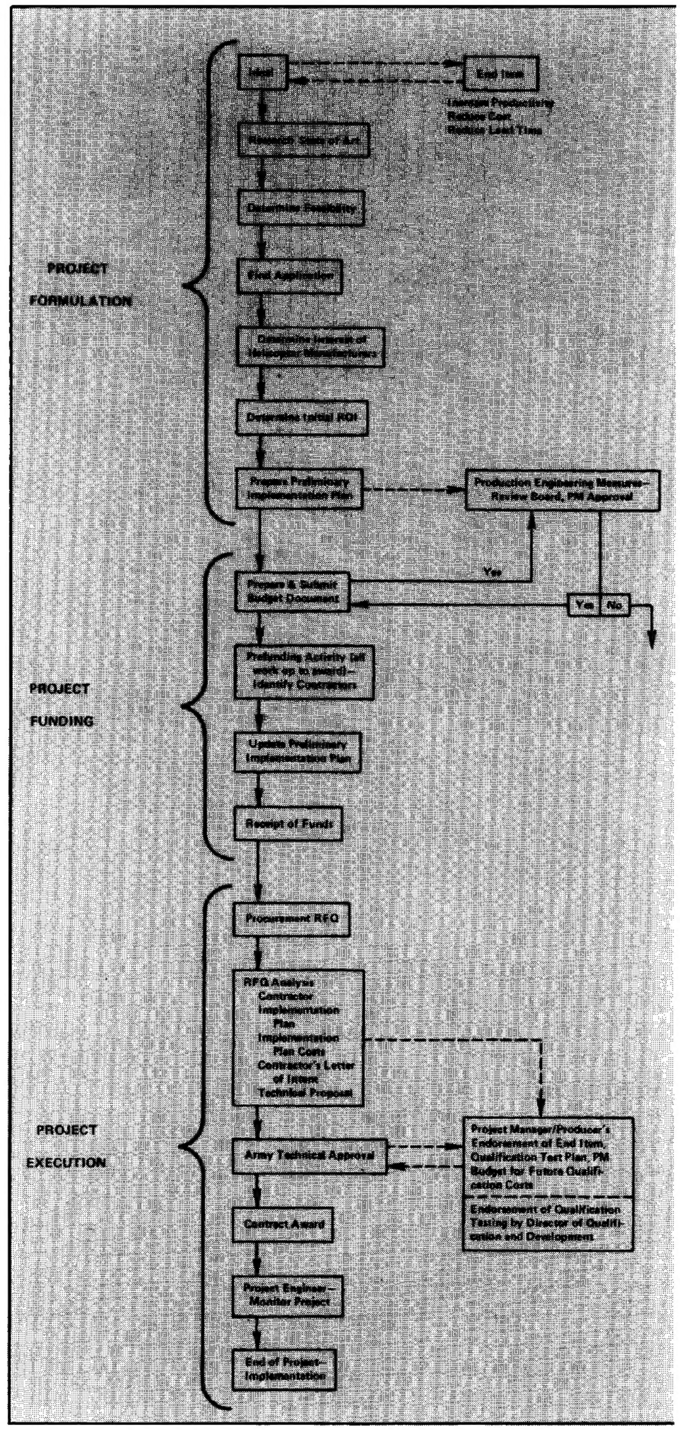


Figure 1

qualification plan. However, in some cases the contractor will be asked, or at lease encouraged, to share such expenses to help implement the technology. For example, this might be done in a case where both civilian and defense applications are evident.

Early Commitment Needed

These efforts are all initiated on the premise that if implementation is not built into the MM&T effort from the outset, the technology will never make it to production. Once a company has committed to some other production process and invested in material and equipment, it is very difficult to get a new technology on the production line, no matter how promising.

In applying this strategy, there are two typical directions in which an MM&T project proceeds at AVRADCOM. In the first, both the manufacturing process and end item are identified during the project formulation stages. In such cases, the prime contractor is usually a helicopter airframe or engine manufacturer who subcontracts the process development.

Alternatively, the manufacturing process may be identified at the outset, with no specific end item application designated. In this case, the process developer is usually the prime contractor. The contractor locates a suitable helicopter component for the process, and the airframe or engine manufacturer becomes the subcontractor.

Compressor Casing

The contour milling operation used to finish the outside of forged titanium compressor casings for the T-700 engine (Figure 2) was an inherently slow operation and very costly. A MM&T program was undertaken to investigate precision casting of the casing exterior to final dimensions. Prior to the contract award, the contractor submitted an implementation plan, which included a written commitment to use the technology developed on the T-700 engine for the BLACKHAWK helicopter. The BLACKHAWK project manager concurred with pursuit of this effort and the contract was awarded to General Electric. No additional funds were required for qualifying the component since such tests were conducted on a piggyback basis.

Successful completion of this project resulted in a direct labor savings of more than 30 hours per unit. Additionally, the titanium casting weighs only 30 pounds compared to the 65 pound weight of the forging used previously. This new technology will result in a savings of $655 per engine on the 250th unit and total savings of at least $5 million, depending on ultimate production. The project cost was just over a half million dollars. An end of contract briefing, attended by both government and industry personnel, provided a vehicle to transfer the technology.

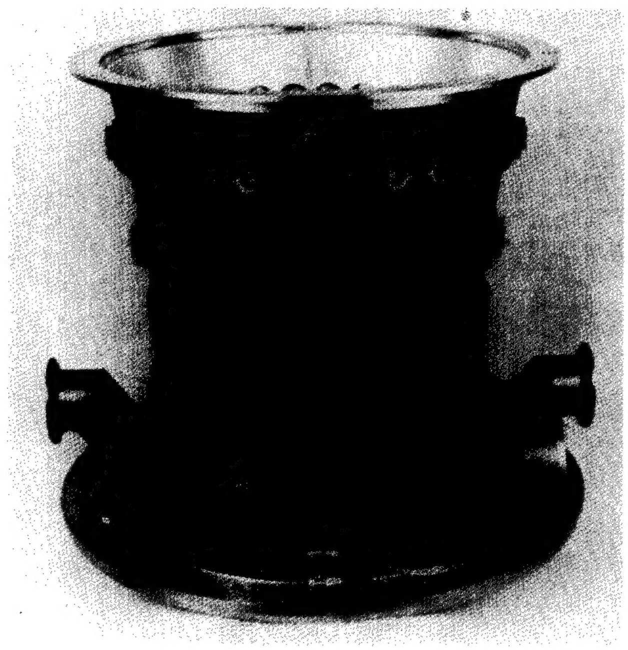
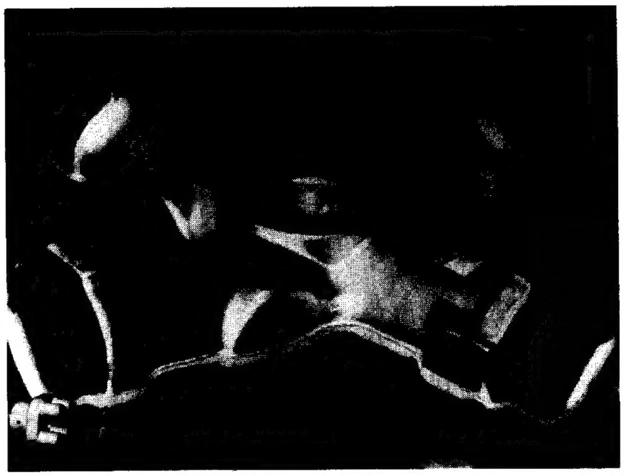


Figure 2

Titanium Casting

An ongoing program is directed to development of precision casting techniques — specifically hot isostatic pressing — for a Ti-6Al-4V main rotor hub for the BLACKHAWK. Development of beta heat treat technology is also a part of the MM&T effort. Current titanium forging technology often requires 8 to 10 pounds of starting material per pound of finished stock. The BLACKHAWK main rotor hub, for example, requires a forging input weight of 1000 pounds, while the finished part weighs only 150 pounds (Figure 3). Preliminary studies indicated that a properly designed precision casting need weigh only 300 pounds prior to machining. The MM&T project to pursue this technology is being conducted by Sikorsky Aircraft.



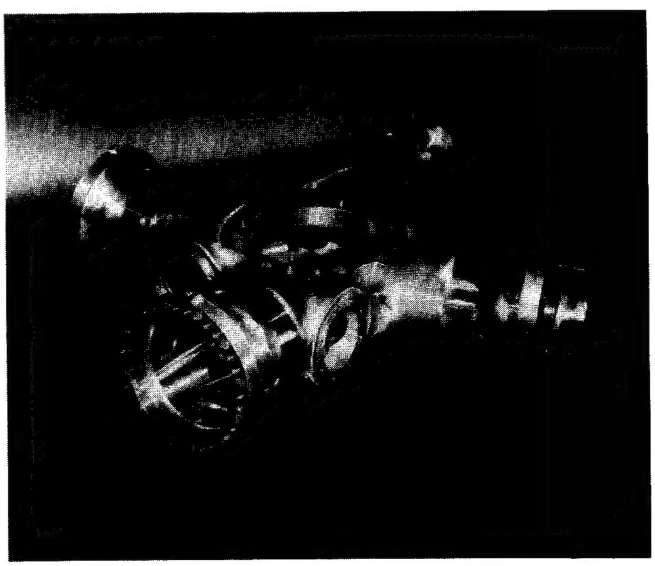


Figure 3

Prior to award of the contract, AVRADCOM had Sikorsky's letter of intent to use the technology that is developed and their implementation plan. The implementation plan was updated 90 days after the effective date of the contract. In the implementation plan, Sikorsky identified all major milestones from the start of the MM&T program through qualification testing and installation of the component on the aircraft. The qualification testing is over and above the scope of the MM&T effort and this part of the plan was reviewed and approved by Personnel of the Directorate for Development and Qualification. Full scale component testing is provided as the final part of the contract.

Under the contract, Sikorsky will submit a final implementation plan 60-90 days after completing the final technical report. At the completion of the project, an end of contract briefing will be scheduled with government and industry personnel for transfer of the technology purposes. The AVRADCOM MM&T project engineer will follow up on implementation and validate cost savings within the first year after project completion.

Aluminum PM Parts

In an ongoing MM&T project, ALCOA is investigating manufacturing methods for production of aluminum airframes and helicopter components utilizing powder metallurgy techniques. Conventionally forged components generally have poor mechanical properties and fatigue resistance and require a large number of manufacturing operations. This program seeks to develop cost effective powder metallurgy forgings that demonstrate superior mechanical properties over these conventional forgings. Specifically, the program is investigating a drive shaft adapter for the CH-47 helicopter. The project is jointly funded by the Army and Air Force with the Air Force Materials Laboratory as the contracting agency. Boeing-Vertol is a subcontractor for Army implementation purposes.

The solicitation for this program was originally initiated by the Air Force with ALCOA. Prime Army helicopter contractors were then asked to furnish cost effective condidate components that would provide an adequate return on investment, could be implemented on an Army helicopter production line, and could be developed within available MM&T funds. Boeing Vertol and the CH-47 drive shaft adapter were selected. This company had submitted a letter of intent to use the technology and is furnishing an implementation plan. The proposed MM&T effort was reviewed and endorsed by the CH-47 project manager. The project includes full-scale component testing as the final effort. Boeing-Vertol will update the implementation plan as required during the investigation and at the completion of the contractual effort. The AVRADCOM MM&T project engineer will validate cost savings and follow up on implementation after the project is completed. An end of contract briefing will take place with government and industry personnel in attendance for transfer of technology purposes.

Applicable to Complex Parts

RF Curing of Epoxy Composites

LAWRENCE C. RITTER is Senior Research Engineer, Advanced Technology, in the Manufacturing Technology Department at the Boeing Vertol Company. He joined the Boeing Vertol Company in 1973 after completing 33 years as a civilian scientist with the U.S. Navy. Over the past 25 years, Mr. Ritter has been engaged in plastics and adhesive qualification, polymer synthesis, thermoset and thermoplastic fiber reinforced organic composite fabrication, test, and evaluation. Mr. Ritter was head of the Plastics Fibers and Adhesives Branch, High Polymer Division, at the Naval Air Development Center, Warminster, Pa., from 1968 to 1973. In this capacity, he was responsible for R & D projects on graphite, boron, glass and organic fiber composites, adhesive formulations, ND testing, and polymer synthesis, all relating to some phase of material evaluation systems, fabrication, and testing. Since joining Boeing Vertol, he has conducted manufacturing development on dielectric heating techniques for curing epoxy resin-reinforced plastics, cost-savings work on manufacturing fiberglass rotor blades, and shop liaison for composite technology. In the past year, Mr. Ritter has been responsible for the manufacturing technology, fabrication, and assembly of glass, organic, and graphite fiber/epoxy NOMEX sandwich construction simulating a helicopter tailboom section. These sections were tested for ballistic survivability. He received a degree in physical chemistry from Temple University in 1958. In addition he has done graduate work in mathematics, polymers, and biochemistry and has received special instruction in plastics, mechanical performance and physical testing, theory and practice, adhesives and adhesion. Mr. Ritter is a member of the American Chemical Society and the American Association for the Advancement of Science.

The feasibility of curing fiberglass reinforced epoxy glass composites by radio frequency (RF) heating using conveyorized equipment has been demonstrated at Boeing Vertol. It was already known that, when the process is applicable, cost savings as high as 75 percent can be realized using RF heating rather than conventional conduction heating to cure epoxies.* Radio frequency curing eliminates the large energy consuming facilities and costly flow times required with present technology.

During Boeing Vertol's study of the process, a conveyor was used to pass a self contained pressurized tool containing the uncured epoxy fiberglass part between flat plate electrodes and through the emitted radio frequency field, as illustrated in Figure 1. This approach can be used to cure complex shapes of varying thickness and permits use of inexpensive nonmetallic tooling.

Boeing Vertol studied the process under an Army Aviation Research and Development Command contract. The study results indicate that radio frequency curing can be applied to specific composite helicopter parts—limited only by equipment design and part geometry.

*J. Mahon, et al, "Manufacturing Methods for Rapidly Curing High Temperature Components", AFML-TR-73-159, August 1973.

NOTE: This manufacturing technology project that was conducted by Boeing Vertol was funded by the U.S. Army Aviation Research and Development Command under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The AVRADCOM Project Engineer is Fred Reed, (314) 263-1625.

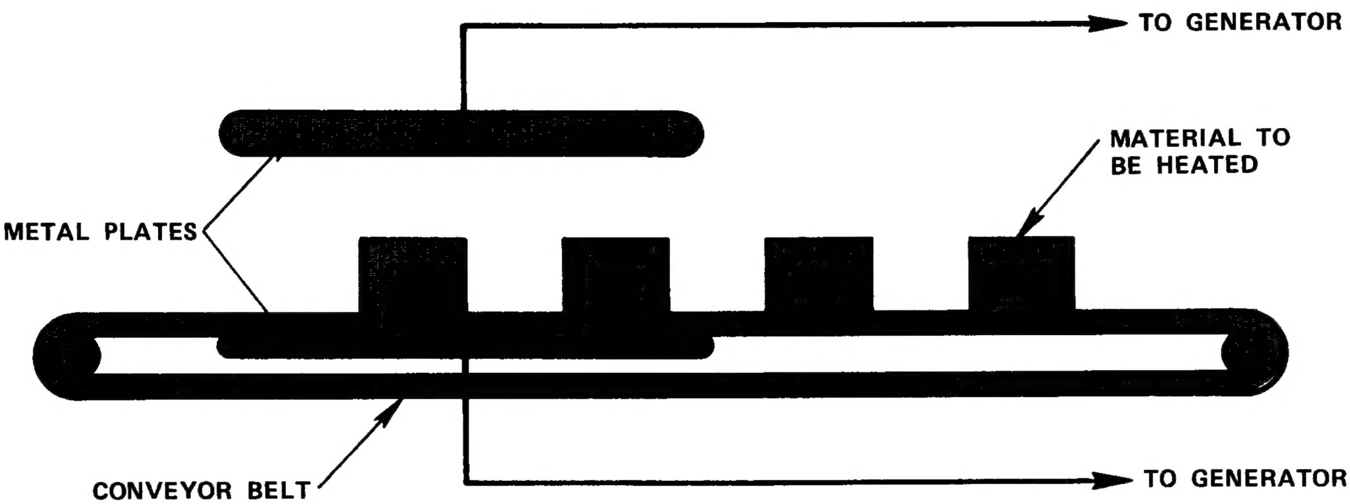


Figure 1

During the program, Boeing Vertol established cure cycles for resin/fiber composites and such process parameters as feed rate, power loads, electrode spacing, and material thickness variations.

Measured mechanical properties of the radio frequency cured composites were in line with appropriate Boeing material specifications. However, Boeing Vertol concluded that use of polysulfone rather than polypropylene as a die material would further improve interlaminar shear properties. The stronger tooling material would allow greater pressure to be applied during the cure cycle and overcome an apparent shortcoming during the feasibility studies.

Molecular Movement Incited

In dielectric heating, which includes radio frequency heating, nonconducting materials are placed in an alternating electrical field. Absorbed energy from the electrical field induces oscillations in the charged components through introduction of rotational kinetic energy to the molecules, resulting in a temperature increase.

The heating effect is directly proportional to the frequency, to the square of the applied voltage, and to the dielectric constant and the loss tangent of the material. Loss tangent describes the capacity of a substance to absorb high frequency energy. As loss tangent increases, more energy is absorbed and the heating effect increases. Conversely, lower loss tangents mean less heating.

In most applications and at a fixed temperature, the dielectric constant and the loss tangent are fairly constant over the dielectric heating frequency range. Therefore, there is no need to seek a best frequency. Rather, the desired heating range is obtained by selecting a frequency range and voltage for which it is practical to build equipment and for which a suitable electrode system can be designed.

Improved Heating

Dielectric heating takes place below a material's surface and heats the entire volume simultaneously. Heating is substantially quicker and more uniform than with conventional methods. Some further advantages of dielectric heating include the following:

- The energy can be turned on and off instantaneously.
- It is efficient in that it does not throw off wasted heat.
- It can be precisely and accurately controlled.
- It can heat selected sections of a part, leaving other sections cool.
- Equipment is easy to operate, is basically long lived, and requires little maintenance.

The basic theory of dielectric heating is to change standard AC line voltage to radio frequency. The high

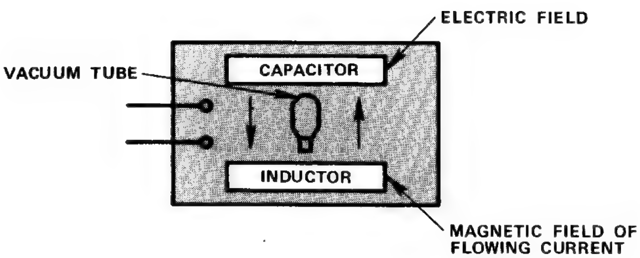


Figure 2

frequency voltages are actually generated in a capacitor—inductor combination, as shown in Figure 2. Energy is stored altermately in the capacitor and in the inductor—in an electrical field in the capacitor and in the magnetic field of the current flowing in the inductor. The current flow in the inductor charges the capacitor to one polarity. When the capacitor is fully charged, the current flow reverses, flowing through the inductor and charging the capacitor fully in the opposite direction. The vacuum tube provides a switch between the power supply and the inductor-capacitor combination, switching current from the power supply at the appropriate times. High frequency voltage—up to tens of thousands of volts—is delivered through a transmission line to the heating unit.

For dielectric heating, two radio frequency ranges are used. For most processes, the frequency is somewhere in the 1 to 200 MHz range, usually called high frequency or radio frequency. For a small but increasing amount of work, frequencies above 890 MHz in the microwave range are in use, buy equipment and operating costs are much higher and the hazards are greater.

High frequency generators are available in a wide range of output power ratings from about 50 watts up to many hundreds of kilowatts. Equipment delivering 2 or 3 kw can be obtained for frequencies up to 200 to 300 MHz; 25 Kw equipment is available at 100 MHz and 100 Kw equipment at 30 to 40 MHz.

Equipment Monitored

For investigation of radio frequency curing, Boeing Vertol used a 20 Kw (90 to 100 MHz) radio frequency dielectric heater. Specifications for the equipment, identified as Model 20/CV/90, are given in Table 1.

Power Output	20 Kilowatts
Electrode Area	22 x 35 Inches
Electrode Spacing	4 to 18 Inches
Frequency Range	72 to 108 Megahertz
Power Line Voltage Required	230 or 460±60 Cycle, 3 Phase
Power Line Current Required	
230 volt operation	100 Ampere, 3 Phase (minimum)
460 volt operation	60 Ampere, 3 Phase (minimum)
Line Voltage Fuses in Machine	
Plate Transformer Fusing	
230 volts	100 Amperes
460 volts	60 Amperes
Control Transformer Fusing	
230 volts	30 Amperes
460 Volts	15 Amperes
Power Tube	(1) THERMALL 6-1
Rectifiers	(6) THERMALL SR 152 (modules)
Safety	Panel Interlock Switches
	Overvoltage Breakdown Protection
	D.C. Overload Protection
	Grounded Case and Frame
Plate Current	4 Amperes Maximum
Grid Current	See Note
Belt Speed	0.5 to 5 feet/minute

NOTE: For ideal operation at 3.6 amperes of plate current the grid current should be 575 milliamperes. Grid current meter is marked in red below 550 and above 800 milliamperes. The white area of the dial from 550 to 800 milliamperes is the ideal operating range for the grid current.

Table 1

The frequency of the equipment was monitored both from inside the building and at a distnace of 2,000 to 3,000 feet outside the building for possible interference with navigational and communication equipment on overhead aircraft or with commercial television and radio transmissions. Measurements taken with the equipment in both the load and no load conditions indicated there was no discernible interference through the 10th harmonic.

To fabricate the fiber reinforced composite laminates for use in the curing studies, Boeing Vertol used Scotchply SP-250-E-33-W-456. A press cured laminate made from this material met all requirements of Boeing's material specification except that of per ply thickness, which was 1/2 mil less than required.

Polypropylene Selected for Tooling

Several monmetallic tooling materials are suitable for use in a radio frequency field. These materials are "transparent" to radio frequencies and have appropriate electrical mechanical, and thermal properties. For this

study, Boeing Vertol considered ceramic, fiberglass/epoxy, polysulfone, poly-4-methyl-pentene-1, silicone rubber, and polypropylene. Silicone rubber and polypropylene proved to be most practical and most economical. Therefore, silicone rubber was used for the inflatable pressure bag and polypropylene for the matched die tool itself. Selection of polypropylene was based on its low dissipation factor (0.0003) and 2.2 dielectric constant. Furthermore, it is readily available, easily machined, and relatively inexpensive.

Although polypropylene's upper temperature capability of 270 to 300 F was of some concern, the tool designers felt that the material's nonheating characteristics with radio frequency and poor heat conductivity would permit the tooling to sustain epoxy cure cycles without difficulty.

The creep and deflection properties of polypropylene were another concern because of the compacting pressure needed during the cure. To resolve this concern, several polypropylene bars were tested in tension to determine the material's strength. Failure occurred at 4,500 psig.

The deflection of a 1 by 1 by 12 inch bar of polypropylene was measured empirically under a static load of 80 pounds at room temperature. Over an 8 hour period the bar deflected approximately 0.070 inch. Once the load was removed, the bar returned to its original horizontal plane overnight. Since these conditions were more severe that those expected in practice, the material was considered acceptable for tooling use.

The tooling used for the curing studies consisted of matched mold dies in three sections machined from polypropylene plate, as seen in Figure 3. The bottom section held the laminate to be cured, the midsection was a floating pressure plate, and the top section contained the inflatable pressure bag.

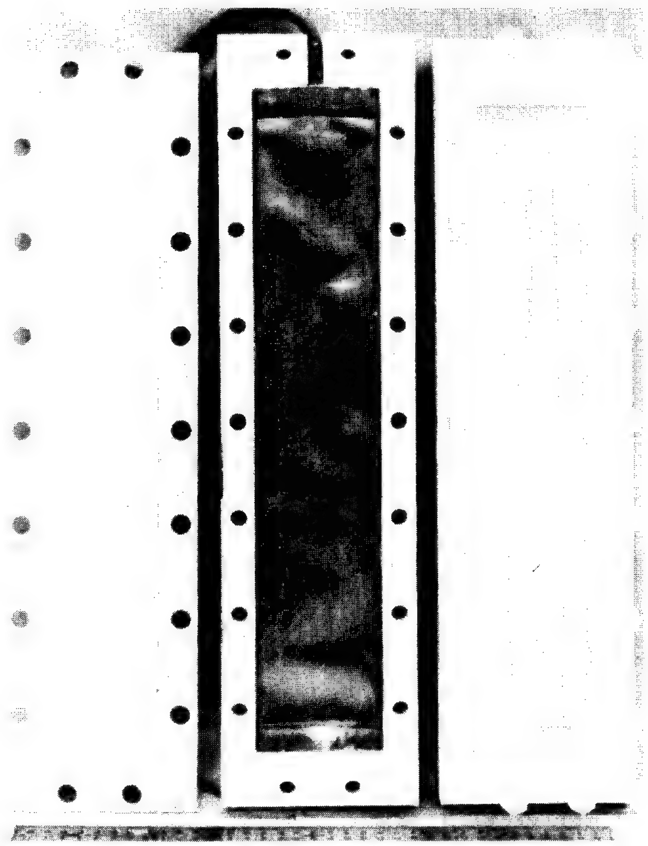


Figure 3

Two Laminate Types Used

To develop radio frequency curing parameters, Boeing Vertol used two basic laminate shapes—a wedge and a constant thickness section. Both shapes comprised 10 sections—alternately thich and thin—with a release material positioned between each.

The wedge shaped laminate, shown in Figure 4, was made from unidirectional fiber sheets, which were stepped off 1 inch for each ply after the first section. To complete the wedge, two halves were faced together, as shown in the figure. The thick sections contained 12 plies—except those at the facing, which were 14 ply—and the thin sections had six plies.

For the constant thickness laminates with unidirectional fibers, the plies were spaced the same as in the wedge shaped sections but were all the same length. However, constant thickness laminates with ±45 or 0/90 degree fiber orientation were also made. On these laminates, all thick sections were 12 ply and thin sections were 8 ply. Thus, there were 104 plies in all, as opposed to 100 in the other laminates.

Die Loading Sequence

To prepare the laminates for curing, the ten separate layups comprising a specific laminated unit were completed and arranged in the proper stacking sequence with a couble thickness of fiberglass bleeded cloth on both the top and bottom. The completed laminate was placed on a piece of nylon bagging material, which was

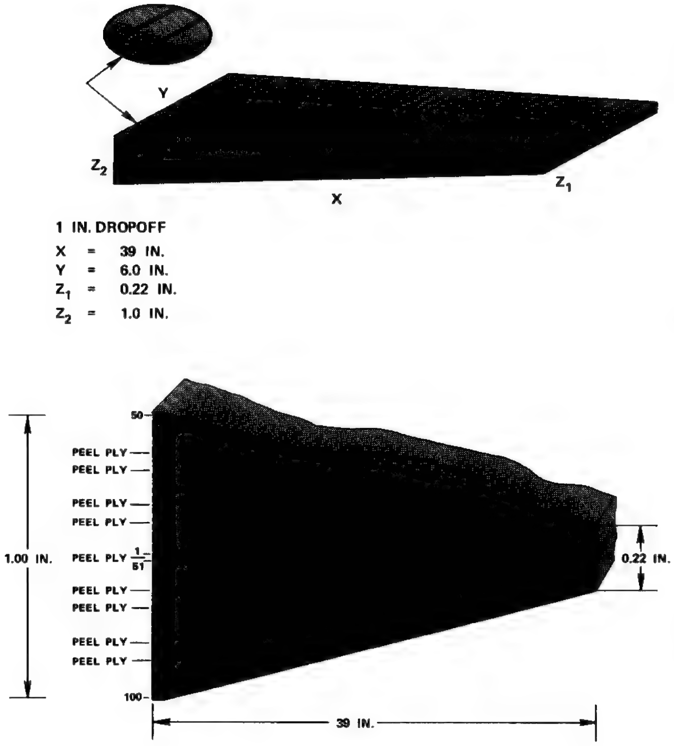


Figure 4

intended to contain resin squeezeout and to preclude time consuming tool cleanup after curing. A second bag of Teflon film was used to seal the seam of the nylon bag.

This bagged unit was placed in the lower die cavity, as shown in Figure 5, and silicone rubber spacers were placed around the edges to facilitate removal after curing. Next, a polypropylene spacer was inserted. The spacer thickness was uniform for the constant thickness laminates, but a wedge shaped spacer was used for the wedge shaped laminates. With the spacer in place, the floating pressure plate and the top die section containing the inflatable silicone pressure bag were positioned. The dies were securely fastened by assembling nuts on the studs of the lower die. An initial pressure of 10 psig was applied to the laminate through the inflatable bag.

The resin containment bag around the laminate was pierced at each of the temperature sighting holes located in the lower die. This allowed controlled flow of squeezeout resin during curing. The resin squeezed out was

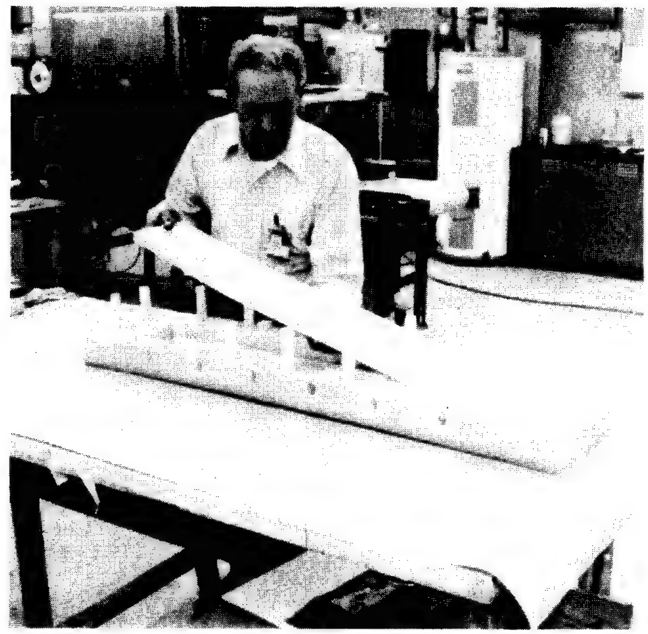


Figure 5

collected in a separate throwaway trough that was attached to the die after it was positioned on the conveyor belt.

Curing At 250 F

Figure 6 shows a loaded tool being placed on the conveyor for transport through the radio frequency curing unit. The parts were cured by cycling the assembly through the radio frequency field between properly spaced electrodes at a controlled speed. For constant thickness sections, the temperature of the laminate increased incrementally to 250 F over a 70 minute period. For wedge sections, the temperature increase to 250 F required 120 minutes. The curing pressure was 30 to 40 psig, applied when the laminate temperature reached 170 to 200 F.

Laminate temperature was monitored by infrared fiber opbics throughout the curing process and changes were recorded on an x-y strip chart. The end of a sensing probe positioned through the oven wall to within 3 inches of the laminate was aligned to sight through the ports on the side of the tool. The probe was connected outside

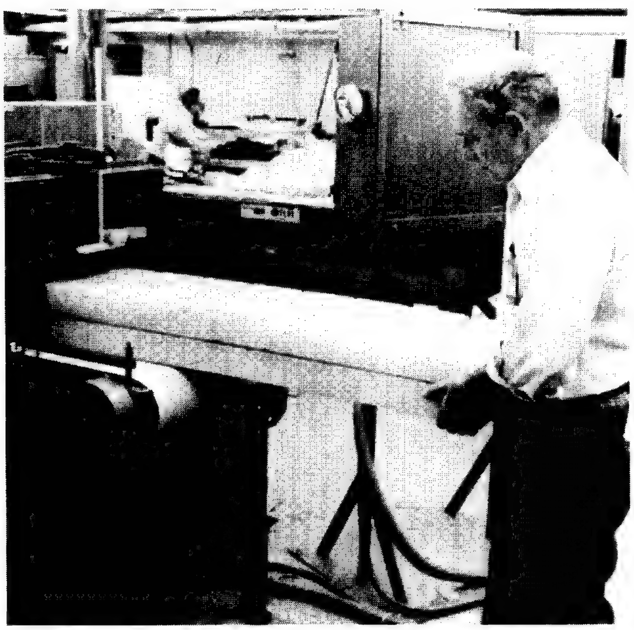


Figure 6

the oven to the detecting head, which in turn transmitted the signal to a digital readout calibrated in fahrenheit degrees. The x-y strip chart was connected to the digital readout.

Wedged Shape Presents Problems

Monitoring the cure cycle of the constant thickness sections presented no particular problem. Thanks to the uniform laminate thickness, temperature increases were evident within 10 to 15 minutes of exposure to the radio frequency field. Temperature monitoring fof the thin edge of the wedge shaped laminates proved more difficult. The temperature readout charts for wedge sections showed aborted pen tracings for the sight ports in the vicinity of the thin end. In early cures, nylon was not used to contain the resin, and the resin buildup at the ports contributed to erratic temperature measurements. Although addition of the bagging helped, temperature measurements at the thin end of the laminate remained erratic.

In a related problem, the last 1 to 2 inches of the thin end of the wedge did not cure in early studies. Experience showed that the tapered portion of the wedge—up to one half the length—required longer radio frequency exposure for a complete cure. On subsequent runs, only the thinner half of the wedge was exposed to the field for the first 30 minutes. To accomplish this, the radio frequency was switched off as the thicker portion of the wedge passed between the electrodes. After this initial exposure, the entire laminate was allowed to cycle through the field for the remainder of the curing cycle. It was also necessary, in some instances, to expose portions of the laminate to a static application of the radio frequency for periods fo 1 to 2 minutes.

Parameters Established

As experience was gained with each successive cure, plate current, grid current, filament voltage, and line voltage were seen to remain constant for a specific load passing through the field at a particular electrode spacing. Experience also showed that the appropriate spacing from the upper electrode to the top surface of the tool through most of the cure cycle is approximately 1/2 inch. When monitors showed the temperature increase to be too rapid, control was exerted by increasing the space between the electrodes to reduce the energy input or by turning off the radio frequency while a particular section of the assembly passed through the electrodes. Thus, for the most part, processing parameters actually resolved themselves to electrode spacing and the intermittent application of the radio frequency field.

Test Results Indicate Feasibility

For practical purposes, mechanical properties of the radio frequency cured composites were commensurate with the requirements of the Boeing material specification used as a standard. Hardness, fatigue properties, beam shear, flexural strength modulus, and tensile strength modulus were measured.

Rockwell M hardness for both the wedge section and constant thickness section panels was measured to determine the degree of cure. Values for the 12 ply laminates gave evidence of a full cure condition for all panels but one. All the 6 ply laminate values, however, suggested that additional cure might be necessary.

Fatigue property data for the radio frequency cured laminates fell slighly below that plotted for press cured laminates. This could be attributed to an undercured resin matrix or to the need for additional pressure during the cure.

Property	Test Temperature
[illegible]	[illegible]

Table 2

Mechanical properties of radio frequency laminates were determined at three test temperatures (65, 74 and 180 F) after exposure to three hostile environments—oil soak, boiling water, and a 180 F soak. A summary of results is given in Table 2. Figures that fall below the required value of Boeing's material specification are underlined.

Examination of the average beam shear values show the majority falling below specified values; the percentage falloff ranged from 3 to 20 percent. Boiling water proved to be the most severe environment for the beam shear specimens. In light of the flexural results, the lower beam shear values seem a paradox. Based on Rockwell hardness, the degree of cure appears acceptable. Also, the source of the specimen (wedge or constant thickness section), its location in the panel, and the stacking location of the panel in the section seemed to have no relationship to individual mechanical property values.

Additional Cure Suggested

Examination of tensile strength/modulus values for unidirectional laminates shows them to be within the acceptable limit of 5 percent of the specified values with the exception of the measurement at 180 F, where there is a 9.0 percent reduction. The tensile strength values relate directly to the laminate resin content. The fact that Rockwell hardness values for the 6 ply laminates ranged from 70 to 90 versus an acceptable 100 value suggests that some additional cure was required.

Tensile strength values for both the 0/90 degree and the ±45 degree fiber orientation were slightly below specification requirements. The value for the 0/90 degree sections at -65 F is low by 10 percent, but the 74 F and 180 F test results are acceptable. For the ±45 degree material tensile values, the 74 F test result is 9.5 percent lower than the specification requirement.

Retests Run

To resolve the differences in results for flexural, short beam shear, and tensile properties, a series of retests was conducted on radio frequency cured panels which were subjected to postcure at 250 F for 16 hours. The resin content was determined for the postcured panels that were used to reevaluate tensile/strength modulus.

A comparison of the results with original test values showed improvements in flexural strength at 180 F and in tensile strength/modulus for 0/90 degree fiber orientation at -65 F. Other values for short beam shear and tensile strength showed no significant improvement. These results suggest that the degree of cure provided by radio frequency energy was relatively complete.

The panels used for tensile test specimens showed a rather wide spread in resin content ranging from 20 to 28 percnet. This variation is difficult to explain, since all panels were subjected to 40 psig pressure during cure.

Curing Pressure Significant

The test results suggested that the ultimate cure pressure may need to be studied further. A pressure greater than 40 psig may be required to obtain a beam shear strength equal to that of press cured laminates. Also, the 40 psig pressure may not have been sufficient to produce low void 12 ply laminates. Although the void content of the radio frequency cured laminates was not determined during this program, with press curing the 40 psig cure pressure resulted in 12 ply laminates with 3.9 percent void content. A high void content would relate directly to a falloff in short beam shear strength.

From these results, Boeing Vertol recommended that tooling for radio frequency curing be made from polysulfone to allow application of greater pressure during the cure and thus improve interlaminar shear properties. This material has better strength and stiffness than polypropylene, has minimum creep, and is capable of withstanding temperatures of 300 to 350 F.

Composite Main Rotor Tubular Braided

One Third Cheaper Than Glass/Epoxy

MARK L. WHITE is Chief, Materials & Process Applications, Kaman Aerospace Corporation, where he has spent the past 22 years of his professional career involved with materials and processing development, characterization of materials, failure analysis, and development of quality control systems. He previously had worked for United Technologies, Hamilton Standard Division, and as a research assistant at MIT. He received his M.S. in Metallurgy from MIT in 1956 after receiving his B.S. in Business and Engineering Administration there a year earlier. He is a member of the American Helicopter Society, American Society of Metals, Society for the Advancement of Materials, Processing, and Engineering, and Sigma Xi. Mr. White is a Registered Professional Engineer in the State of Connecticut.

Mechanical tubular braiding is now a viable blade spar manufacturing process after completion of a program which included preliminary design of an improved main rotor blade for the OH-58 helicopter. The blade incorporates an advanced aerodynamic shape and has as its primary structural member a Kevlar 49/epoxy spar fabricated by braiding. Achievement of an analytically acceptable blade and spar design meeting critical structural and dynamic requirements was not hindered by braiding process constraints.

Mechanical property tests of flat panels and spar sections exhibited excellent correlation with analytical predictions, substantiating the applicability of normal composite laminate analysis methods and the validity of the specific design.

Ballistic testing of spar sections demonstrated superior containment of structural damage compared to composite spars produced by more conventional methods.

Manufacturing cost estimates predict a price reduction of one third for the braided spar over a similar S-glass/epoxy spar fabricated by orthodox low cost technology for an OH-58 blade of identical external shape.

Kaman Aerospace Corporation and the U.S. Army Aviation Research and Development Command, in their ongoing efforts to enhance helicopter blade operational characteristics and reduce manufacturing costs, have

NOTE: This manufacturing technology project that was conducted by Kaman Aerospace Corporation was funded by the U.S. Army Aviation Research and Development Command under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The AVRADCOM Project Engineer is Mr. Fred Reed (314) 263-1625.

undertaken preliminary design and process development of a composite improved main rotor blade for the OH-58 helicopter. This design is unique in that the blade spar is fabricated by mechanical tubular braiding.

This program was sponsored by the Aviation Research and Development Command and monitored by the Army Materials and Mechanics Research Center. Kaman, the prime contractor, was assisted in the development and application of braiding technology by Albany International Research Co.

New Levels of Performance

Fiber/resin composite construction has engendered a new generation of helicopter blades of vastly improved operating characteristics, reliability, and maintainability. Prepreg layup processes have been employed for blade spar fabrication and, more recently, filament winding has been introduced as a lower cost, automated manufacturing technology.

Mechanical braiding is an established textile process for weaving a tubular fabric that has been employed for more than a century in fabricating products such as rope, hose, and cable assembly overlays. Recently, it has also been adapted to composite fabrication, predominantly in light duty or nonstructural applications such as aircraft ducting.

Figure 1 shows a conventional 96 carrier braider which was adapted for the fabrication of composite structure and used for braided spar development.

This modification consists essentially of a mechanism for translating a mandrel through the machine at a controlled rate. In operation, the spools of fiber revolve on carriers around the stationary outer ring, half in each direction, passing over and under each other to produce a tubular fabric. This fabric, which in normal braiding has an over-two, under-two pattern similar to a twill weave, is deposited on the mandrel. Mandrel pitch, or distance of translation per revolution of the braider carriers, controls the fiber orientation angles, a situation which is geometrically analogous to filament winding.

Flexibility A Feature

Either preimpregnated roving or dry fibers which are subsequently impregnated may be employed together with conventional curing on the mandrel to produce the composite structure.

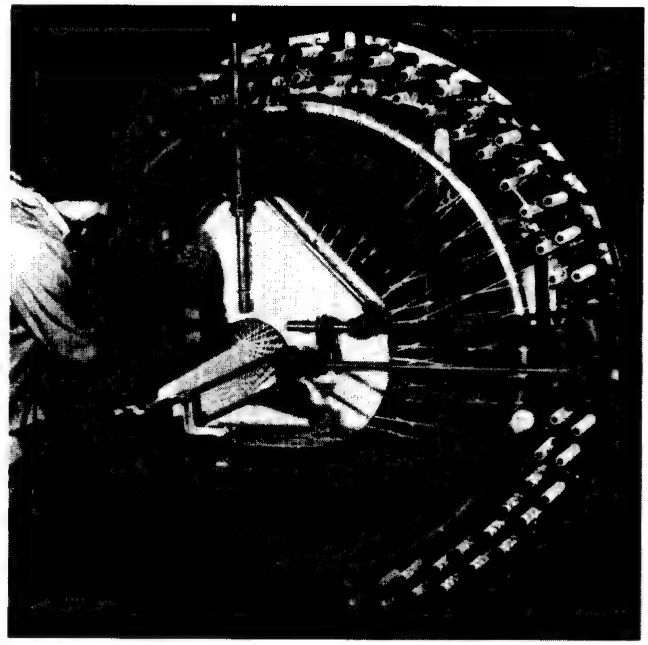


Figure 1

As an alternative to previously employed blade spar manufacturing processes, braiding has a capability for laying down interwoven fibers at substantially higher rates. As demonstrated in the present program, these characteristics produce enhanced resistance to ballistic damage and reduced manufacturing costs.

Blade manufacturing begins with braiding of dry roving on an aluminum alloy mandrel having the tip weight attached at the outboard end. This weight is, in effect, a part of the mandrel which becomes a permanent part of the spar. The dry braided spar assembly (with inserted doublers and leading edge filler) is then vacuum impregnated with a liquid epoxy resin in a matched tool to provide accurate control of resin content. Spar and blade afterbody details are cocured in a matched steel mold. Mandrel withdrawal is performed before the addition of the bushings, closures and trim weights to complete the blade. The use of hard internal mandrels and external molds assures precise contour fidelity and weight control, and is the same basic tooling concept proven in the AH-1 helicopter composite blade production program.

Interwoven Structure More Tolerant

An OH-58 blade shape having an advanced aerodynamic geometry developed in an earlier Kaman study was used as a basis for the braided spar blade design. Cost studies and ballistic testing performed on the S-glass/epoxy wound spar design developed in that program afforded an opportunity for direct, meaningful comparison of relative cost and ballistic tolerance between filament wound and braided spars.

Fabrication trials, flat laminate mechanical property tests, spar section structural and ballistic tests, and nondestructive inspection evaluations were conducted. In the course of the program coupon test panels and two seven foot spar sections were fabricated.

Conventional laminate analytical methods accurately predict the performance of composites produced by braiding. In analyzing the braided composite, each braided layer was replaced by two laminae of half layer thickness, one representing the positive, and one the negative fiber angles of the bidirectional fabric. The validity of this procedure was subsequently verified by mechanical property testing.

The interwoven structure of a braided spar laminate contains the extent of ballistic damage to a greater degree than does the more limited interweaving of a filament wound structure. (Both are ballistically more tolerant than laminates of angleplied unidirectional prepreg.)

One spar section was impacted with a .30 caliber fragment simulator projectile which penetrated through both walls of the spar. Visually apparent damage did not extend much beyond the actual projectile hole and ultrasonic inspection, described below, revealed roughly circular areas of delamination extending up to one inch beyond the holes. Static retesting of the spar section in flapwise bending and torsion to limit loads showed no detectable changes in elastic properties, and resulted in no apparent extension of the damage.

Fracture Characteristics Improved

A second spar section was struck with a fully tumbled .50 caliber armor piercing projectile in a manner duplicating as closely as possible a similar test performed on the S-glass/epoxy wound spars. The projectile exit surface of the braided spar revealed damage extending only slightly beyond the actual puncture. In comparison, the conventionally fabricated fiberglass spar exhibited extensive fracture and brooming of spanwise fibers and delaminations extending several inches beyond the point of impact.

Inspectability is an important characteristic of any composite blade design. A C-scan, through transmission ultrasonic inspection technique which is commonly used for inspecting other composite spars is adequately sensitive to discontinuities in braided composite spars.

Cost Savings Certain

Detailed estimates of average spar prices in production runs of 500 units were prepared for the braided Kevlar spar and the similar wet filament wound fiberglass spar. Table 1 summarizes these estimates, which predict a 33% price saving to the customer for the braided Kevlar spar in comparison to the filament wound glass version.

Further, wet filament winding was chosen as the lowest cost, established composite spar manufacturing process. Therefore, even greater savings would be expected versus other methods, such as tape layup.

ITEM	BRAIDED SPAR	FILAMENT WOUND SPAR
[illegible]	[illegible]	$ 171
[illegible]	[illegible]	1126
[illegible]	[illegible]	43
[illegible]	[illegible]	1487
[illegible]	[illegible]	$735,500

Table 1

Developing New Uses for Composites

Organic Materials Lab In Forefront

DR. GEORGE R. THOMAS is Chief of the Organic Materials Laboratory at the U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts. Before his present appointment in 1972, Dr. Thomas was Chief of the Materials Research Laboratory for four years after working fourteen years in the textile and footwear division at Natick Laboratories. He is the National Leader on the Technical Panel Cooperation Program on Organic Materials which includes the United States, Great Britain, Canada, and Australia. He also serves on the National Materials Advisory Board and is a member of several national professional societies. Dr. Thomas received his Ph.D. in Organic Chemistry from Northwestern University after taking his B.S. in Chemistry from Bowdoin College. He also has attended the Harvard Business School and the National War College.

No Photo Available

NOTE: The manufacturing technology projects that are conducted by the Organic Materials Laboratory of the U.S. Army Materials and Mechanics Research Center are funded by the U.S. Army Commodity Commands under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The Composites Division Point of Contact is Dr. Bernard M. Halpin, (617) 923-3100.

Army MM&T personnel, particularly those from the Aviation Research and Development Command—look to the Organic Materials Laboratory at the Army Materials and Mechanics Research Center for help and advice on a total range of problems relating to composites, polymers, and other organic materials. The lab's capabilities include processing, testing, characterization, quality assurance, analysis, and evaluation. It is the only such Army facility equipped to handle a problem of any complexity in the field of organic materials.

Higher Performance With Energy Savings

The principal objective of the Laboratory is to replace heavy, metal components with lighter, more durable parts whenever possible. This can increase survivability of equipment, while providing significant energy savings during manufacture.

The importance of organic composite MT applications has been well documented in previous issues of the ManTech Journal. Aircraft turbine engines with composite accessories have logged millions of hours of flight time powering the Army's helicopters. Also, composite helicopter rotor blades presently reflect the current state of the art, achieving advanced strength, stiffness, and geometric variations offering improved performance, greater survivability, and improved reliability and maintainability with lower production and service costs. Composite helicopter transmission housings and flight controls have been demonstrated to reduce noise and resist ballistic damage. The UH-60A Black Hawk Army helicopter contains more than 551 pounds of such advanced composite materials.

Wide Scope of Materials And Services

The Organic Materials Laboratory (OML) builds and experiments with starting materials, develops and modifies semifinished goods, and tests and evaluates finished goods. Present research is directed toward five classes of materials:

- Composites—glass, fiberglass, graphite, Kevlar, and laminated films
- Plastics—transparent and opaque; also films and coatings
- Rubber—natural and synthetic
- Adhesives—structural and transparent
- Foams—rigid and flexible.

Processing Capabilities

OML has developed a wide range of fabrication techniques and machinery. Through the process of film blowing, continuous lengths of plastic are made. This film gains added strength by being heated and stretched.

Plastics are placed in the blown film line extruder in pellet form. The extruder melts and forms the pellets into a cylinder which is inflated by air to produce a tubular film. (Plastic trash bags are made this way.)

This film is then processed on the film orientation line, where it is heated by infrared ovens and stretched to align the molecules. (See Figure 1.)

In this manner, considerable strength is achieved in one direction. By cross laminating several sheets together, it is possible to fabricate a material with strength in many directions.

Thermal molding is used to produce aircraft canopies and secondary structures for helicopters. A sheet of heated plastic is pushed down over a mold and held in place by vacuum. The plastic stays in one position as it cools and solidifies into the desired shape.

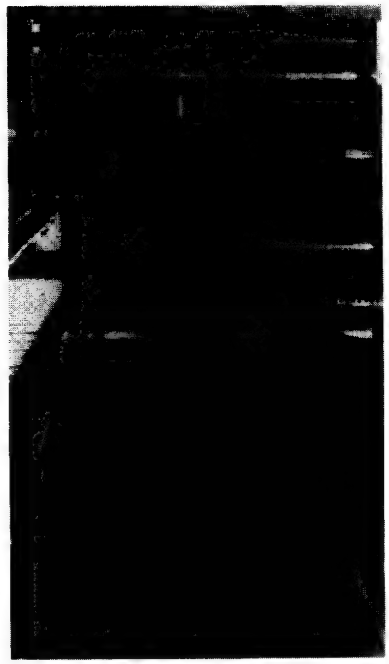


Figure 1

Two types of injection molders are used: reciprocal screw and plunger. Plastic, in pellet form, is heated to its softening point, then injected into a mold where it solidifies in the desired shape. Plastic and plastic reinforced test pieces are made here. Plastic rocket fins having greater aerodynamic efficiency can be made through the injection molding process.

Composite Sheets From Prepregs

OML uses two methods of fabricating composite sheets from preimpregnated resin fiber systems that have produced portable structures and rotor blades and specially designed parts for helicopters. The prepregs contain Kevlar, graphite, boron, or glass, and are stored in a freezer to prevent resin aging. In hand layup, prepregs are overlapped in various patterns and wrapped in a bleeder cloth which absorbs excess resin. They are cured in an autoclave that combines heat and pressure. An automatic tape layup system is also available.

OML has also monitored a program for hot layup tooling, a new low cost tooling adapted to fabrication of an aft engine fairing for the OH-6A helicopter.

The hot layup tool, originally developed for high energy rate forming of metal parts, is fabricated from wire reinforced concrete with a nickel liner. Adoption to composite fabrication required the inclusion of integral heating and cooling elements.

The hot layup tool is basically a male or female, low cost, self heating and cooling tool in which composite materials are laid up and cured.

There is also the closed die configuration (Figure 2) for the hot layup tool in which matched nickel faced male and female dies are used together to effectively serve as an autoclave. But an actual autoclave with its heating and pressurizing systems is not required.

The OH-6A fairing design uses inner and outer skins of Kevlar-49 cloth impregnated with epoxy resin. E-glass has also been used—the mold design can be varied.

The major areas of cost savings are labor and heat energy. The hot layup tooling uses heat energy directly and only when needed. Thus, it is more thermodynamically efficient than oven curing, therefore much less costly.

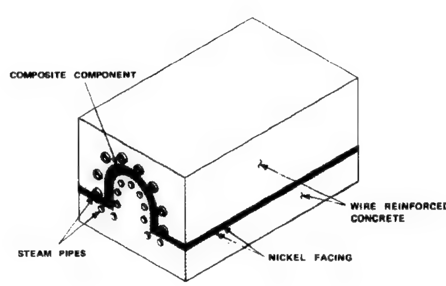


Figure 2

Filament Working And Pultrusion

Filament winding is an accurate process of fabricating reinforced composites. Glass, plastic, graphite, and carbon fibers are used in filament wound parts, examples of which are telescoping launch tubes, recoilless rifles, and beams for assault bridges.

In addition, OML was among the first to fabricate a composite drive shaft. Because it is made with graphite fibers, the shaft is very stiff and lightweight. OML also assisted in the fabrication of a short range, man portable antitank weapon. The antitank weapon tube is much lighter and easier to handle than a World War II bazooka.

There are two types of filament winders at OML, a mechanical winder and an electrically controlled one. As a piece is wound, it is coated with a resin and put into a forced hot air oven to cure (see Figure 3).

An added advantage for filament wound parts is that they have a higher impact resistance than steel ones.

Continuous reinforced composites are produced by the simple process of pultrusion.

Fibers (Kevlar, glass or graphite) are coated in a resin bath and are molded into the final shape by a die. The finished item may be postcured to increase desired properties.

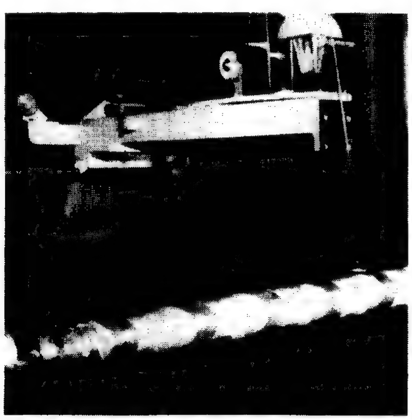


Figure 3

Bumpers, seat slats, and portable bridge components can be made by pultrusion.

The polymer evaluation unit is used to study the processing of experimental materials on a small scale. The unit consists of an extruder, a press, a plunger injection molder, a blade mixer, and an ultraviolet aging oven. The optimum processing conditions for a materal can be determined with a small quantity of material. This is particularly important when costly experimental materials are being evaluated.

Extensive Testing

Fiber reinforced composites are tested under pressure, stress, and strain. A fatigue cycler measures the response of Kevlar, graphite, and fiberglass reinforced epoxies to an oscillating load.

Ultrahigh speed photography and ballistic equipment are used to test the strength of composite armors. Also tested are fabrics, yarns, and transparent and opaque polymers that can be used in protective shields, helmets, and vests. Environmental chambers allow the tests to be carried out in temperatures ranging from below 60 F to over 200 F.

The flammability test laboratory seeks to reduce the amount of fire damage by screening newly developed polymers and composites before they are used in structures. The laboratory can test materials to be used in major building projects. If they are found to be highly flammable or smoke easily, other materials can be used.

By using instruments in the laboratory, OML scientists simulate various environments to study composite degradation.

Resistance to Laser Attack

OML researchers are trying to select materials strong enough to withstand high energy lasers and light enough to be practical.

Steel and other metals are no match for lasers, but some composites provide strong resistance. These materials will be used primarily in aircraft. Carbon fiber composites selectively are being used to stiffen a helicopter's rotor blades. Attack helicopters need windshields that will protect against both ballistic and laser weapons.

Carbon-carbon, a new high temperature resistant material, can be used in the nosecaps of rockets. It resists burning during reentry into the earth's atmosphere.

The laboratory is equipped with furnaces, a gas chromatograph, and a reactor system for testing.

Quality Control of Prepregs

Epoxy resins and prepreg systems also have been evaluated at OML. Strict quality control is vital, both to ensure quality fabrication and to study deterioration of the product. Work at OML has demonstrated the value of high pressure liquid chromatography in this regard.

The high pressure liquid chromatograph analyzes milligram amounts of samples in a very short time and can be used for qualitative or quantitative analysis. Impurities in resins or hydraulic fluids can be identified and materials of unknown compositions can be analyzed.

Gel permeation chromatography, light scattering, osmometry, and viscometry are techniques also used in solution characterization.

Spectroscopy is yet another characterization technique. Through spectroscopic analysis, it is possible to fingerprint a material.

In a major breakthrough achieved in July, 1975, Fourier transform spectroscopy made it possible for the first time for a researcher to follow all changes of characteristics and properties of an epoxy resin material as it went through its cure cycle—before, during, and after. This new capability has provided a quantum leap forward in organic composite formulation and development. The impact on composite research has been dramatic, and this

revolutionary influence will continue to be felt in the future.

The laboratory is equipped with a complete range of spectrometers including Fourier transform, infrared, high resolution nuclear magnetic resonance, laser Raman infrared, and mass.

Another technique of polymer analysis has been developed combining gas chromatography and mass spectroscopy.

These characterization techniques show the degree of cure and aging of prepregs, effects of cure conditions on the oxidative stability of the resin, products of degradation, and effect of processing on the chemistry of the resin systems. The effects of various environments are also tested.

Nondestructive Evaluation Advances

Nondestructive testing techniques are used to evaluate changes in a composite's properties during the cure cycles. Much of the work is directed toward helicopter rotor blades.

One of the most promising techniques is acoustic emission testing. When a load is applied to a sample material, it emits stress waves, otherwise known as acoustic emissions. These emissions are produced by movement and breakage of fiber and matrix. The emission signals are measured and matched against a preset threshold.

A second method used is ultrasonic testing. Ultrasonic waves are directed at helicopter blades, but since the waves will not pass through voids, cracks and defects can be discovered before the blade is attached to the helicopter.

X-rays are also used to look for delaminations. Nondestructive testing techniques also provide researchers with a better understanding of the effect of processing parameters such as cooldown rates on the properties of a material.

Handbook Being Compiled

A manufacturing handbook on nondestructive inprocess inspection of composite structures for helicopters is in preparation by OML for the Aviation Research and Development Command. the handbook will list the type of structures, the type of inspection methods to be used, the defects to be tested for, and the acceptance/rejection criteria to be applied.

Work also is being done to develop polymers and advanced composites resistant to high temperatures as an alternative for metals.

These materials retain the strength of metals but are lighter and are particularly useful in aircraft and missiles.

OML is currently testing polyphenylquinoxalines (PPQ's), polymers that are resistant to very high temperatures; unlike other high temperature polymers, PPQ's soon may be easily processed.

Thermogravimetric analysis and differential scanning calorimetry are used to evaluate these advanced polymers.

OML also is studying the problem of fiber release from composites used in aircraft and ground vehicles by using thermal analysis.

Since the fibers are highly conductive they could cause power failures if they escape into the open environment. Researchers are trying to develop a high temperature resistant resin to prevent this potential hazard.

Applications Important

Many practical applications of OML's work have been demonstrated. An armored vehicle equipped with steel wheels and tracks was crippled by a direct mine blast. However, a tank with composite wheels and tracks sustained less damage and remained mobile. The wheel is made of polyurethane, while the track shoe is structural foam and polyester.

A composite gun barrel extension that will reduce whip and increase accuracy has been developed.

The extension is made of a steel liner reinforced by graphite epoxy. Because the composite extension is 18% stiffer than the conventional extension, it whips less; also, it is 20% lighter than its all steel counterpart.

OML also is developing and testing improved lightweight armor.

Transparent armor is usually made by laminating layers of glass, plastic, or ceramic materials.

The armor is used to protect the pilots and aircrew of attack helicopters from enemy fire. It can also be used in the windows of government officials' cars. Many commercial banks use Army-developed transparent armor to protect employees.

Members of OML have teamed up with the College of Engineering at the University of Lowell to test composite solar energy collectors.

Kevlar cables may soon replace steel cables in structures such as antennae masts and suspension bridges.

The Kevlar cables are lighter, easier to work with, and nonconductive so they will not interfere with transmission.

Composite materials have been proposed to augment an all aluminum bridge which is attached to a vehicle and can be unfolded over a river or valley, providing mechanized units a quick, safe crossing (see Figure 4).

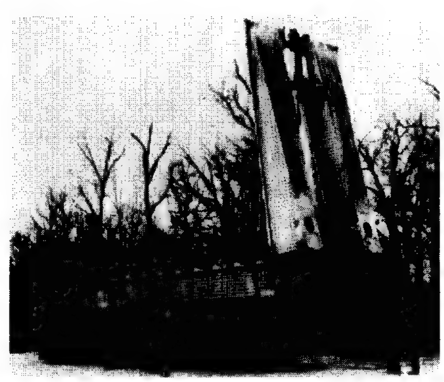


Figure 4

The replacement of the conventional aluminum tent frame with a stiffer and 40% lighter composite frame is another OML project. The composite frame will be more portable and have greater durability.

Scientists and engineers of OML are developing applications for piezoelectric effects in polymers.

Piezoelectric simply means "pressure electric." Researchers can fabricate polymer films that create currents when pressure is applied.

The possible benefits from polymers with piezoelectric effects are far reaching. Piezoelectric fuses can be used in artillery shells.

Piezoelectric polymers can be used as vibration sensors on gearboxes to pick up signals.

Figure 5 shows another application: a noise cancelling microphone in helicopters and tanks. The occupants of these vehicles have difficulty communicating because of the extremely high background noise. This microphone permits transmission only within a few inches of its surface, thus cancelling out all noise outside that range.

Piezoelectric polymer film could be made into a medical sensor. When attached to a person's finger, the sensor receives and generates a charge to record the pulse rate.

Figure 5

Surface Analysis for Flaws

Surface analysis is used to examine the first few atomic layers of sample mateials. Through this inspection it is possible to discover foreign materials or flaws in the surface of the material.

ESCA (electron spectroscopy for chemical analysis), SIMS (secondary ion spectroscopy), and Auger electron spectroscopy are used for surface analysis. All of these techniques are conducted in a vacuum chamber to prevent air interference (see Figures 6 and 7).

Surface analysis is also helpful in detecting defects created by environmental exposure.

Figure 6

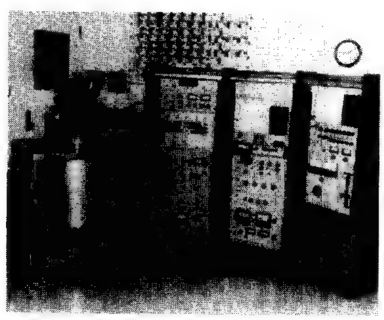


Figure 7

Inductively Coupled Plasma Spectrometer An Advance

A recent addition to the Polymer Research Division is an inductively coupled plasma spectrometer (ICP-ES) used chiefly for the analysis of inorganic components of materials (see Figure 8).

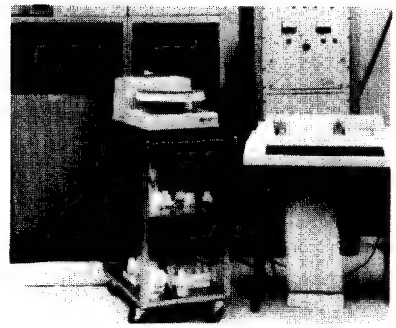


Figure 8

This instrument has the sensitivity of atomic absorption instruments (AA) and is capable of determining the presence of many (up to 40) elements simultaneously by direct reader output.

Due to its much hotter temperatures (7,000 to 15,000 C versus 3,000 C for AA including flame or furnace atomizer) much greater atomization can be achieved, especially from refractory elements such as phosphorus, boron, zirconium, and uranium.

The high dynamic range of the ICP-ES in conjunction with proper selection of elemental wavelengths allows major and trace elements to be simultaneously determined.

Microscopy Heavily Used

Microscopic examination of polymers and composites serves to detect structural irregularities and flaws to aid scientists in the design of better processing methods.

Materials are examined at various stages. The behavior of resins and catalysts, as well as that of prepregs during the processing cycle, is observed.

The laboratory is equipped with three different microscopes.

The transmission electron microscope is used to study the internal structure of a material. It can magnify up to 100,000X.

The scanning electron microscope (Figure 9), which magnifies up to 50,000X, is used in the study of bulk polymers and surface features.

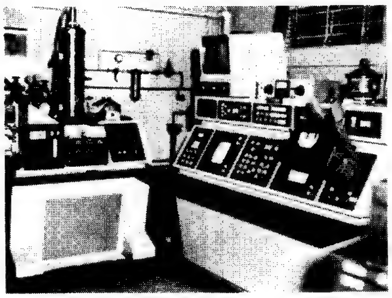


Figure 9

The light optical microscope (magnification up to 1,000X) is used to study the distribution of solid particles in polymers. For this purpose a polarized light interference attachment is also used.

Moisture Effect Studied

Scientists at OML are trying to determine how water, in liquid or vapor form, penetrates the composite and affects the mechanical properties. The measurement of weight and size changes is used for this purpose.

An analytical microbalance measures weight gains in small samples. For larger samples, the standard linear dilatometer measures the change in length of one dimension at a time. In humidity chambers, the samples can be subjected to varying degrees of temperature and moisture.

Solubility, diffusion, and permeation measurements are also recorded. Most of the testing is done on resins used in helicopter rotor blades.

The ultimate goal is to establish a mechanism to determine how water penetrates a composite and then migrates.

Increased Composite Utilization Foreseen

OML has taken positive steps to be at the leading edge of technological and manufacturing advances in the 1980's. The Army Aviation Research and Development Command has developed a comprehensive 5 year plan for aviation mantech efforts, with assistance from Battelle's Columbus Laboratories in formulating a course of action which relies heavily on composite R & D for helicopter improvements. A number of factors will contribute to the increased use of composites rather than metals in a variety of structural and nonstructural applications:

- A significant part count reduction, reducing assembly time and eliminating joining by rivets
- Automatic or semiautomatic equipment providing the potential for significant labor reduction
- Wide variety of available materials providing an opportunity to select those with the specific characteristics needed for a particular application
- Reduction of facilities costs
- Reduction of machining operations, which are inherent in metallic construction
- Elimination of corrosion problems, reducing repair and maintenance
- Ability to easily produce complex, one-piece parts that would have to be produced by joining multiple pieces if made from metal
- Low energy requirements for fabrication when compared to metal processes
- Conservation of materials due to less scrap in built-up components (10 percent) as opposed to 35 percent for machined-down metal components
- Amenability to joining by adhesive bonding and to a combination of separate operations
- Significant potential weight reduction (35-75 percent)
- Fatigue lives three to ten times greater than those of conventional materials reduce repair and maintenance
- Wide variety of available forms such as fibers, tapes, sheets, foams, etc.
- Ability to combine attributes of more than one material in a structure by selective reinforcement
- Capability to offer ballistic and foreign object damage tolerance, reducing repair and maintenance.

The Battelle study also projects the use of composites as the predominant material for future rotor blade construction.

In addition to the advantages already cited for airframe structures, two advantages of composites, peculiar to their application in rotor blades, are:

- The slow, soft failure mode of fiberglass, which gives an aircrew enough warning to prevent catastrophic crashes.
- The ability to aerodynamically and structurally tailor a blade to optimize performance, flying qualities, stresses, and dynamic response.

Because of the failure characteristics of fiberglass reinforced composites, more widespread use of these materials can be anticipated. The use of higher modulus materials, such as graphite and boron, will continue to be limited to reinforcing those portions of the blade where increased stiffness is required.

The field of composites holds a bright future in these and other areas. Cost reductions will play a key part in the application of composite technology, with such reductions following increased experience with composite materials. OML will help lead the way in composites research, development and testing.

Brief Status Reports

NOTE: All the Brief Status Reports in this section are ManTech projects sponsored by AVRADCOM under the guidance of the Office of Manufacturing Technology.

Application of Thermoplastic Helicopter Secondary Structures. AVRADCOM is developing manufacturing process to expand thermoplastics for full scale secondary structures at lower cost compared to epoxy composite or metallic counterpart components. For additional information, contact Ling Chien, (314) 263-1625.

Isothermal Roll-Forging Of Compressor Blades. AVRADCOM is developing manufacturing technology for isothermal roll forging of precision compressor blades. The work is being performed at Solar. Roll forging will replace the conventional blade manufacturing process. Recently, the isothermal roll forging machine setup was modified for blade airfoil forging. An atmosphere enclosure on the machine prevents burnup of the graphite lubricant during forging. Surface contamination of AM-350 roll forgings by the graphite forging lubricant was studied. This study showed that forgings made in 15 seconds at temperature are contamination free except at the point of initial die contact, where high current densities and overtemperature resulted. Technology Laboratory, Ft. Eustis, Va. is the principal investigator. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

Cost Effective Manufacturing Methods For Improved, High-Performance Helicopter Gears. This program is concerned with ausrolling, in combination with improved nondestructive evaluation methods to provide a means to optimize quality, reliability, and cost of high-performance helicopter gears. This program is being conducted in two phases. Phase I provides for improved processing methods for manufacture of high-performance, high-quality gear materials. The work will incorporate advanced manufacturing methods such as ausrolling and would center on producing gears of 9310 steels. Phase II provides for improved finishing via cold rolling of gears. Results of the program will be consolidated into a GEAR Producibility and Technical Data Package (Guide) for high-performance gears. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

Cast Titanium Compressor Impellors. Technology for fabricating titanium compressor impellers by casting and hot-isostatic pressing is being developed to replace the current method of machining impellers from forged billets. Mechanical properties of the cast material are improved by hot-isostatic pressing. Final machining is by either mechanical or chemical milling. The new method of fabrication will reduce production costs by 40 to 50 percent by substantially reducing billet waste and reducing machining costs. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

MM&T High Quality Superalloy Powder Production for Turbine Components. This project will establish an improved industrial procedure for producing high-quality superalloy powders to be used in the manufacture of hardware for gas turbine engines. Initial efforts are directed at removing nonmetallic inclusions from the earliest stages of melting. Subsequent efforts will be directed toward eliminating impurities from the powder making process. More than one powder making technique will be included. Techniques for cleaning impurities from the powder will be scaled to handle production lots. The final part of the program will be devoted to preparing process and product control specifications. Product evaluation will be carried out with specimens removed from hot isostatically pressed or forged parts representing turbine engine hardware. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

MM&T: Titanium PM Compressor Impeller. This program will develop the technology to HIP a near net shape centrifugal compressor impeller from titanium powder. Benefits are higher material utilization and superior properties. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

MM&T: High Temperature Vacuum Carburizing. This project will establish high temperature vacuum carburizing as an alternative to current production methods. By raising the process temperature, the length of the process cycle will be shortened, yielding an economic advantage. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

MM&T: Processing of Advanced Gear Materials. The object of this program is to demonstrate a capability of producing high quality gears of a given configuration by developing a heat treat procedure (vacuum car-

burizing) for Vasco X-2 which will provide equal or better reliability and longeuity than Vasco X2 gears currently heat treated to a gas carburizing proprietary specification. For additional information, contact Mr. Gerald Gorline, (314) 263-1625.

Microwave Cure of Composite Rotar Blade Spays. The objective of the project is to establish procedures for the use of microwave energy in the cure of thick sections of composite materials. Establishing parameters for the use of microwave power in curing composites will permit much shorter cure cycles and will result in energy savings. For additional information, contact Mr. Dan Haugan, (314) 263-1625.

Composite Rear Fuselage Manufacturing Technology. The primary objective of this program is to develop manufacturing processes for fabricating molded composite primary fuselage structures. A secondary objective is to develop quality assurance and nondestructive inspection criteria for molded composite primary structures. For additional information, contact Mr. Dan Haugan, (314) 263-1625

MM&T: Filament Winding Resin Impregnation System. Current resin impregnation process control is on the order of ±4 percent in terms of fiber/resin ratio variance. The purpose of this project is to develop a resin impregnation control system that will provide control on the order of ±2 percent or better. By achieving consistency in the fabrication of composite structures, the current 4-to-1 margin of safety can be reduced. This will in turn reduce the weight and cost of composite structure fabrication. This work, being performed by Bell Helicopter Textron, will result in resin impregnation control system specifications and a breadboard control system. For additional information, contact Mr. Dan Haugan, (314) 263-1625.

Semi-Automated Composite Manufacturing System for Helicopter Fuselage Secondary Structures. A program to demonstrate a semi-automated manufacturing system for the production of helicopter secondary structural components made from composite materials is under way. The Grumman Aerospace Automated Composite Laminating System, developed for the Air Force, will be modified as required to accommodate selected AAH and/or Black Hawk composite secondary structures. Contractors for these helicopter systems will select their respective aircraft components for subsequent automated fabrication. Detailed structural characteristics/configuration, materials development and qualification testing will be performed by the AAH and/or Black Hawk contractors. Coordination meetings with the Air Force, Army, Grumman Aerospace, Hughes Helicopters, and Sikorsky Aircraft have been conducted. Grumman is conducting a fabrication cost analysis on input provided by Hughes L. Thomas Mazza, Applied Technology Laboratory, Ft. Eustis, Va. is the principal investigator. For additional information, contact Mr. Dan Haugan, (314) 263-1625.

MM&T: Filament Wound Composite Flexbeam Tail Rotor. This project will develop filament winding manufacturing technology for fabrication of flexbeam tail rotors. Techniques and processes to be established include not contour winding, improved resin control, and continuous filament winding from open to closed sections. The ultimate task to be accomplished lies in fabricating composite flexbeam tail rotor blades by the wet filament, cocuring method for the YAH-64 helicopter (AAH). The ultimate objective is to develop and refine the manufacturing processes and perform the testing needed to demonstrate the feasibility of the tail rotor blade so that it may be considered for incorporation in the production program for the AAH. For additional information, contact Mr. Dan Haugan, (314) 263-1625.

MM&T: Structural Composites Fabrication Guide. This program will establish a production manufacturing guide for advanced composites aircraft and engine structures. The GUIDE will provide a production analysis of the capabilities and limitations of many types of manufacturing processes that may be used with advanced composites. It will also provide process/cost interrelationships for current manufacturing processes and establish process selection techniques. For additional information, contact Mr. Dan Haugan, (314) 236-1625.

MM&T: Pultrusion of Honeycomb Sandwich Structures. Honeycomb sandwich panels are used extensively in composite airframe structures. At this time, production of these panels is labor intensive. This project will develop production methods for these honeycomb structures using ceramic pultrusion dies. For additional information, contact Mr. Dan Haugan, (314) 263-1625.

Ultrasonic Weld of Helicopter Fuselage Structures. The objective of this project will be to develop and optimize the ultrasonic welding manufacturing process techniques and to verify the potential cost savings of ultrasonic welding over conventional welding and joining processes. Present welding and joining methods are labor intensive and time consuming. This new welding method will solve such problems. For additional information, contact Mr. Bruce Park, (314) 263-1625.

MM&T Ultrasonic Assisted Machining. The objective of this project is to determine the increased productivity and cost reduction attainable by using ultrasonic energy assistance to machine superalloys and difficult-to-machine materials. Candidate materials have been selected by canvassing aircraft and turbine engine manufacturers. Cutting parameters such as feed, speed, and cut depth will be determined for ultrasonically assisted machining. Cost effectiveness of this technology for making production helicopter parts will be evaluated against conventional methods and conclusions will be drawn regarding capabilities of the process capability. For additional information, contact Mr. Bruce Park, (314)263-1625.

Surface Hardening of Gears, Bearings, and Seals. This project seeks to develop and demonstrate the use of lasers for heat treating and surface hardening gear teeth (now case carvurized). This new heat treatment process will improve the impact strength and fracture toughness of gear teeth and reduce their manufacturing costs by requiring less energy, eliminating quenching dies and possibly eliminating finish grinding. Druing the course of the work, heat treating processes will be optimized and control parameters will be established. For additional information, contact Mr. Bruce Park, (314) 263-1625.

MM&T: Composite Engine Inlet Particle Separator. The current fabrication process for the T700 inlet particle separator (IPS) involves machining of castings and forgings and joining of these parts — an expensive process. This project proposes the fabrication of the (IPS) from injection molded thermosplastics composite, combined with high modulus/high strength thermo- - setting composite (graphite-polyamide). For additional information, contact Mr. Bruce Park, (314) 263-1625.

Precision Forged Al P/M Helicopter Components. This project is a joint effort with the Air Force to develop manufacturing technology for direct pressing of newly developed aluminum powder metallurgy materials into precision forged helicopter components. The project offers potential means for reducing the number of manufacturing steps (compared to conventional forging) and increasing fatigue properties of the component. For additional information, contact Mr. Bruce Park, (314) 263-1625.

Superplastic Forming of Titanium For Helicopter Component. This project was the highest rated proposal received by the Airframe Panel at the Army Aviation ManTech Conference. Its primary objective is to establish a production base and verify process reproducibility for the superplastic forming/diffusion bonding (SPF/DB) process. This process will be applied to helicopter firewalls and engine access panels. Process variables will be firmed up and a production run to determine costs and reproducibility will be made. The project will reduce component fabrication and assembly costs, as well as the weight of the structure. For additional information, contact Mr. Bruce Park, (314) 263-1625.

Integrated Blade Inspection System. The objective of this project is to inspect certain T-700 Airfoil Parts with a high degree of accuracy. Presently hand, airflow, waterflow, or light inspection methods are being used that are labor intensive, time consuming and susceptable to error. The new and automated Visual Inspection module, Infared Thermography, and X-Ray

Tomography techniques will solve such problems while reducing costs. For additional information, contact Mr. Bruce Park, (314) 263-1625.

MM&T: T-700 Turbine Engine Manufacturing Process. Project objective is to develop processing techniques and the necessary fixtures to produce small air cooled turbine engine nozzles such as those found in the T-700 engine. For additional information, contact Mr. Joe Pratcher, (314) 263-1625.

Non-Destructive Evaluation Technique For Composite Structures. A manufacturing handbook on nondestructive in-process inspection of composite structures for helicopters is being compiled. Initial data will be developed for a composite rotor blade. Once the data are obtained, they will be applied to other composite structures. Depending on the configuration and stress levels in the structure, various criteria will be established for acceptance or rejection based on number, type, and size of the measured defects. The proposed handbook will list the types of structures inspected, the type of inspection methods to be used, the defects to be tested for, and the acceptance/rejection criteria to be applied. For additional information, contact Mr. Joe Pratcher, (314) 263-1625.

Integrally Heated And Pressurized Tooling For Rotor Blades. Present technology for composite rotor blade fabrication calls for a time-consuming series of operations involving vacuum bag sealing and autoclaving of the material. This project will establish criteria for integrally heated and pressurized tooling to replace autoclaves in the process. The proposed process would eliminate the use of vacuum bag material by having an integral bag in the tool. The tool would be used as the cure fixture. Integrally heated and pressurized tooling will permit rapid heat-up and cool-down rates so that cycle times will be reduced. For additional information, contact Mr. Joe Pratcher, (314) 263-1625.

Engine Nozzle In-Process Inspection. The objective of this project is to develop nondestructive test techniques for examining assembled T-700 engine nozzles for flow blockage and determining air flow volume. Automatic electrical measurement devices will be developed, as well as holding fixtures to group nozzle segments as a full assembly. A prototype automatic flow area measuring device with digital display and printed readout has been developed. This project will speed the necessary area measurement and flow control checks, thereby reducing operational cost. The end products of the project will be nondestructive test equipment and test techniques developed for the solution of inspection and quality control problems associated with small, air-cooled, turbine nozzles. For additional information, contact Mr. Joe Pratcher, (314) 263-1625.

Fabrication of Integral Rotors by Joining. This project will establish the manufacturing technology for fabrication of integral rotors by joining the blade and disks via metallurgical bonding. This would eliminate the expensive machining required for mechanical attachment. For additional information, contact Mr. Joe Pratcher, (314) 263-1625.

MM&T: Abradable Seals For Turbine Blade Tip Applications. The efficiency of gas-turbine engines such as the T-53, T-55, and LTS-101 can be improved significantly by building a replaceable, abradable seal into the turbine shroud. Operating and maintenance costs can be reduced as well. A method for manufacturing abradable seals is being investigated by AVRADCOM through AMMRC. The project is based on the extension of the effective use of abradable seals in the compressor section of large gas-turbine engines. This process will eliminate the precision machining necessary for providing the critical clearance required between the blade tip and the case shroud. For additional information, contact Mr. Fred Reed, (314) 263-1625.

MM&T: Manufacturing Techniques For Helicopter Transmission Shaft Seals. Transmission seals are a continuing problem and one of the main reasons for early removal of transmissions. A promising approach to obtaining high-speed capability at low cost is the synergistic seal, which is a combined segmented carbon and elastomeric seal. The prime objective of this approach is to produce a low cost, high-speed seal at about one-third the cost of conventional high-speed seals. By installing segmented rings into

an elastomeric member much of the precision machining of the mechanical seal can be eliminated. The purpose of this manufacturing program is to develop processes and techniques for molding the elastomeric element around the segments and to develop means to closely control the roundness and taper of the carbon bore and shaft outer diameter. For additional information, contact Mr. Fred Reed, (314) 263-1625.

MM&T: In-Process Continuous Balancing of Helicopter Shafting. When long, hollow shafts (such as tail rotor drive shafts) are not perfectly balanced, bearing supports are subjected to excessive stress; and, in the case of shafts designed to operate at super-critical speeds, the shafts themselves are subjected to severe loading when running near resonant frequencies. The purpose of this one-year project is to build and demonstrate an automatic machine for the balancing of long hollow helicopter shafting. The end result of the project will be a shaft balancing machine to be used during production of shafting for both current and future Army aircraft. For additional information, contact Mr. Fred Reed, (314) 263-1625.

Stabilized Line of Sight Gimbal Production. This project will develop manufacturing techniques required to fabricate inner gimbals for stabilized line of sight systems from composite materials with improved mechanical strength and lower weight. Tooling and methods developed will permit major geometric variations with minimal costs incurred for re-tooling. This program will permit the use of a basic stabilized system whose inner gimbal can be cheaply modified to accommodate different electro optical payloads. For additional information, contact Mr. Fred Reed, (314) 263-1625.

MM&T: Braiding of Reinforced Plastic Structural Components for Helicopters. This technology will develop the manufacturing technology for braiding primary and secondary helicopter structures. Braided structures have greater strength than filament wound or tape layup structures because the interwoven fibers retard cracks, delaminations, and separations. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

Hot Isostatic Pressing Ti Casting. The objective of the program is to reduce material waste and machining time. This will be accomplished by HIP of a cast black-hawk titanium rotor hub. Post pressing heat treatments will be included to improve fatigue strength to match that of current forgings. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

Efficient Machining Methods and Cutting Tools for Kevlar Composite Structures. This project will develop tooling and methods to achieve basic machining operations on Kevlar laminates. Present methods tend to cause delamination and excessive fuzzing/fraying of the Kevlar cut edges, necessitating the use of time consuming, and repetitive techniques to achieve acceptable machined surfaces. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

MM&T: Composite Tail Section. This project will develop filament winding manufacturing technology for fabricating airframe tail section components. Reduced weight and cost and improved field repairability will result from this effort. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

MM&T Composite Main Rotor Blade. The objective of this program is to manufacture a new composite main rotor blade for incorporation in the production program for the AAH. The blade concept will be based on the wet filament winding cocure process. It shall be static and fatigue tested, whirltower tested, and flight tested to demonstrate MM&T success. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

Lightweight Composite Fasteners For Helicopter Systems. This will develop production methodology for composite fasteners applied to assembly of composite helicopter components. This technology is needed to maximize newer composite mateials which offer the benefits of lighter weight and lower cost, promoting improved system performance. For additional information, contact Mr. Jim Tutka, (314) 263-1625.

Top Priorities Outlined

TACOM II Conference A Success

Two hundred sixty attendees from seventy-two companies and five Army agencies attended the U.S. Army Tank Automotive Command's Military Vehicle Manufacturing Technology Conference II held June 28-July 1 in Dearborn, Michigan. Over one hundred eighty potential projects were reviewed and discussed by five separate panels as some two hundred presentations were given by attendees.

Major General Oscar C. Decker served as General Chairman of the Conference; Cochairmen were Colonel Herbert Dobbs, Director of the Tank and Automotive Systems Laboratory at TACOM, and Frederick J. Michel, Acting Chief of the Office of Manufacturing Technology at the Materiel Development and Readiness Command. John L. Baer, Director of the Chemical and Mechanical Engineering Division of the Office of Manufacturing Technology, assisted the Cochairmen. General Decker introduced Mr. Gerald C. Meyers, Chairman and Chief Executive Officer of American Motors Corporation, who was guest speaker at the luncheon given on the second day. Dr. James Chevalier, MM&T Program Manager at TACOM, headed up the Program Committee planning the Conference, assisted by Raymond L. Farrow of the Army Materials and Mechanics Research Center and James Carstens of the Army Industrial Base Engineering Activity. Ms.

NOTE: This Manufacturing Technology Conference was conducted by the U.S. Army Tank Command under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The Point of Contact for further information on the conference is Mr. David J. Pyrce, Conference Secretary, (313) 574-5000.

ɩusan Armstrong of Battelle-Colum-
ɩus was Conference Coordinator.

Five Panels Meet

The purpose of the Conference was o obtain suggestions from industry n potential manufacturing technol-gy projects. The Conference was rganized in the form of simultaneous anels on: Transmission—Dallas Gritton of Detroit Diesel Allison, Chairman; Engine—Charles Kuintzle of AVCO/Lycoming, Chairman; Hull & Turret—Jake Neu of Chrysler Defense Inc., Chairman; Track & Sus-ension—John MacRostie of FMC Corporation, Chairman; and Tactical Vehicles—George Bugarin of TA-COM, Chairman.

Four Goals Set

Each panel chairman and his assis-ants evaluated various proposals and ade suggestions of priorities to ACOM. These results will be re-orted in more detail in an article ter in the Fall by David J. Pyrce of ACOM, Secretary of the Confer-nce. The article will be based upon Final Report which will be sent to ll attendees, and also other inter-sted parties who contact Mr. Pyrce.

Several general priorities were de-ned at the panel meetings, with the ecommendation that future efforts oncentrate on automation in manu-cturing; increased work on laser etalworking of all categories n exciting new possibility is the use f hard coatings applied via lasers to roduce extremely hard, durable urfaces on critical wear sites, such s the bearing surfaces of tracked ehicles, in order to extend their ndurance under severe conditions; significant achievement in laser technology since the last conference in 1976 has been the evolutionary development of laser welding on the recuperator of the AGT 1500 turbine that powers the Army's M-1 tank—see the Army ManTech Journal, Volume 4/Number 1, p. 12. This new technique slashed the welding cost for that item by more than half, illustrating sharply the profound effect that implementation of lasers in our manufacturing technologies will have in coming years.); a third area of priority is development of robotics with greater machine intellect—devices that will sense changing conditions of processing and adapt the program automatically to respond; a fourth priority is a more intense program of development of welding systems, including welding of aluminum armor.

Eight firm proposals are under consideration so far, with several others likely to be considered for funding. These all are expected to impact heavily on MT activities in the Command during the coming years.

Laser Impact Felt

One of the most significant developments during the five years since TACOM Conference I is in the area of noncontact gaging. This does not reflect merely a change in priorities, but a quantum jump in technology brought about by sophisticated metrology based on laser measurement. The use of this technology in the measurement of the M-1 tank hull has made the final inspection of these hulls an approximate forty minute affair, down by a factor of sixty from the forty man-hours required by older, less automatic methods of certification.

Interdisciplinary Approach Used

Manufacturing/Produc

At MIT

DR. LEWIS ERWIN is an Assistant Professor in the Department of Mechanical Engineering at MIT, where he teaches and conducts research in polymer processing. Earlier, he taught in the Department of Mechanical Engineering at the University of Wisconsin; he is a Registered Professional Engineer in the State of Wisconsin. Dr. Erwin received the Ralph R. Teetor Award given by the Society of Automotive Engineers in 1977 and has twice received the Best Technical Paper Award given by the Extrusion Division of the Society of Plastics Engineers. The Society of Manufacturing Engineers presented him with their 1981 Outstanding Young Manufacturing Engineer Award. A graduate of MIT with S.B., S.M., and Ph.D. degrees in mechanical engineering, Dr. Erwin is a member of the Society of Rheology, the Society of Plastics Engineers, the American Welding Society, and the Society of Manufacturing Engineers; he is an associate member of the Society of Automotive Engineers and the American Society of Mechanical Engineers.

Utilizing an interdisciplinary approach and a concentration of manufacturing know-how, MIT's Laboratory for Manufacturing and Productivity is making solid contributions to the advance of manufacturing technology in the U. S. Improvements in cutting machines, processes and tools; new NC programming methods; a new casting process; and metal forming techniques using intelligent machines are among the many innovations credited to the Laboratory in recent years.

The Laboratory's prime thrust is improved productivity. In an increasingly competitive world market, higher productivity is becoming a key to survival, as well as to an improved standard of living. U. S. manufacturers know this only too well, as they strive to keep abreast of technology improvements in other industrialized nations. Increasingly, they are finding practical help through university-based research.

Ivory Tower Gone

Often maligned in the past for its ivory tower approach, the academic world in recent years has shown increasing willingness to tackle the nitty-gritty problems of industry and an ability to find some practical solutions that step up production. At the same time, industry has become more aware of what the universities can contribute.

The Laboratory for Manufacturing and Productivity is a prime example. Geared toward advancing the science and technology of manufacturing, this center for research and education provides industry with innovative process and product concepts. Equally important, the Laboratory's broad educational program helps meet the need for scientists and engineers—in a variety of disciplines—who are ready and able to analyze manufacturing problems and issues. At present, more than 30 faculty members and 80 graduate students are involved in Laboratory projects.

Strong Challenge

The modern concept of manufacturing and productivity encompasses technical, economic, regulatory, and societal issues. Addressing the many problems that evolve presents a strong challenge. Simultaneously meeting the demand for steadily improved productivity greatly increases that challenge. It becomes obvious that industry resources are not sufficient to tackle these problems alone. One place to turn is to the universities, which, in partnership with industry, labor, and government, have much to offer toward meeting the challenge.

In such a partnership, the university can provide the disciplined approach necessary for new conceptual and scientific developments and can educate a talented group of professionals in the manufacturing field. Industry can translate the ideas and prototypes into production models, machinery, and manufacturing systems. Labor can participate in the development and assimilation of new technologies and ensure the well-being of workers in safe, satisfying, and productive manufacturing environments. Government can provide a regulatory and economic atmosphere conducive to innovation and can foster research aimed at breakthroughs in productivity. The cooperation and interaction of all these institutions is essential if significant results are to be achieved. The Laboratory for Manufacturing and Productivity represents a large-scale commitment by MIT toward that end.

Changing Trends

The recent interest in manufacturing problems within the academic community represents a reversal of a long-time trend. Since World War II the role of science in engineering practice has grown dramatically. This growth has been particularly evident in educational institutions. In the

ity Lab Innovative

1950's, engineering faculty members with Ph.D.'s became the norm and the role of faculty members switched from that of engineer/practitioner to one of engineer/researcher. This change was also evident in the areas of engineering study that were emphasized. In departments of mechanical engineering, fields directly related to the analysis and understanding of designs grew under government funding as the direct application of the theories of mechanics and thermodynamics led to improvements in defense and, later, health care technology. Those fields without a disciplinary orientation and a well-developed theoretical base—including manufacturing—languished. As a result, we find that many people operating manufacturing facilities today are not formally trained for that role.

Efforts such as that at MIT mark a much needed reversal in that trend. If we are to maintain our economic, political, and military leadership, manufacturing engineering must advance. In other nations where productivity is rising at a rapid rate, such as Germany, strong university-based manufacturing research centers are a key factor.

Objectives Spelled Out

With a similar role in mind, activities of the Laboratory at MIT are directed toward:

- Establishing a rational base of knowledge concerning manufacturing productivity by:
  - —Acquiring a fundamental understanding of manufacturing systems, including the complex interactions among such factors as choice of design, materials and process, quality control, market acceptance, durability, environmental impact, and worker safety.
  - —Developing a scientific understanding of manufacturing processes through physical and mathematical modeling of processes; characterization of materials, tools, and machines; and research into the interactions among functional requirements, specifications, and costs.
  - —Establishing a new "axiomatic" approach to manufacturing decision making to facilitate rational design of products and optimization of manufacturing systems.
- Developing, in cooperation with industry, innovative manufacturing processes to maximize productivity and to conserve energy, materials, and human resources.
- Expanding the national talent base in manufacturing science and technology through undergraduate, graduate, and postgraduate education, curriculum development, and seminars and workshops for practicing professionals.

SOME PAST PROJECTS OF MIT'S MANUFACTURING AND PRODUCTIVITY LABORATORY

Fundamental research on mechanics of cutting tool wear
Development of longer lasting metal cutting tools
Tool wear sensors for automated production processes
New cutting processes and machines
A method for preventing sliding wear of metals and polymers
Development of reaction injection molding
Use of electrical-mechanical forces in mixing viscous fluids
Perfect mixing of powders
Direct processing of thermoplastic powders using heterogeneous dielectric properties
Fundamental studies of new processes such as electrochemical machining and laser welding
Automated inspection of parts utilizing acoustic interferometry
New NC programming methods for small job shops and computer graphic systems for NC tape verification
A new process for casting metals
Development of the theory of accelerated testing
A method for monitoring the moisture content of plastics during processing to ensure parts quality
Intelligent machine metal forming techniques
New solvent removal techniques
New methods of processing composites
Development of an axiomatic approach to design of products and processes
Characterization of the rheological properties of composites

- Strengthening institutional relationships with industry, labor, and government in order to improve the educational program and to coordinate and guide innovative research in manufacturing.

Earlier Efforts Continued

Establishment of the Laboratory represented a continuation of MIT's strong commitment to research and education in the field of manufacturing. This commitment, which dated from the founding of the Institute, has resulted in a large number of significant contributions to manufacturing.

Pioneering research at MIT in the early 1950's led to the development of the first numerically controlled machine tool. Later work produced the well-known APT language for the programming of parts on NC tools. In the late 1950's and early 1960's, MIT once again pioneered efforts in the areas of computer graphics and computer-aided design. Among the many innovations during this period were the Sketchpad system, the forerunner of modern computer graphics, and Coon's surface patches, a means of representing complex surface shapes, which is still in wide use in computer-aided design systems.

Program Scope

The Laboratory conducts a wide variety of research programs by undertaking projects for individual sponsors under arrangements tailored to fit specific situations. In recent years, efforts have covered a broad range of basic and applied research areas, exemplified by those in Figure I. Current research projects at the Laboratory fall into nine major areas:

- Axiomatics
- Polymer processing
- Flexible materials processing
- Machine dynamics
- Manufacturing resources
- Intelligent machines
- Tribology
- Computer-aided design and manufacturing
- Metals processing

In the axiomatics area, MIT seeks to establish a conceptually new approach to manufacturing decision making, an approach designed to facilitate rational design of products and optimization of manufacturing systems.

The Laboratory has also established cooperative research programs in several fields of science and technology. These programs provide an opportunity for groups of industrial firms and, in some cases, governmental agencies to benefit from highly innovative, interdisciplinary research and development work. Selection of research topics in these cooperative programs is based on industrial relevance, scientific and engineering interest, educational merit, and relationship to the needs of member firms. Among the cooperative programs are:

- **The MIT-Industry Polymer Processing Program**, established in 1973, provides a center for interdisciplinary research in polymer processing. Current efforts address both fundamental understanding of polymer behavior and development of innovative polymer processing techniques.
- **The MIT-Industry Flexible Materials Processing Program** concentrates on generic issues concerning the physical behavior and processing characteristics of flexible materials, such as fibers, apparel, textiles, paper, and footwear.
- **The Machine Dynamics Program** focuses the resources of MIT in the areas of kinematics, structures, dynamics and control, wear, vibration, sound, and psychophysics. Its goal is the development of technology necessary to design a new generation of industrial machines possessing increased versatility, improved reliability, and better operating characteristics.
- **The MIT-Industry Manufacturing Resources Program** addresses such problems as the design of resource-conserving manufacturing processes, the development of new analytical tools to investigate manufacturing systems, and the creation of rigorous methods to analyze the social aspects of manufacturing.

In addition to its research activities, the Laboratory also sponsors seminars and workshops in such fields as computer-aided design and manufacturing, cooperative research, and energy use in manufacturing.

Utility Stressed

Obviously, transfer of research findings and technology from the Laboratory to sponsoring organizations is a key element in any success of the Laboratory. Toward this end, formal review meetings on each program are held quarterly to evaluate progress and to review goals. However, more frequent informal meetings and conversations have proven useful in accelerating the interchange of ideas in the research process. Ways to improve the speed and effectiveness of technology transfer are a major consideration in the Laboratory's periodic internal management reviews.

Furthermore, in order to meet its objectives and maintain a record of innovative research and development, the Laboratory must serve both the needs of government and industry and the educational goals of MIT. To assure that the program remains consistent with these needs, the Laboratory established an Industrial Advisory Board, comprising leaders in the manufacturing community. The Board's functions are analagous to those of a corporate board of directors—to provide advice on policy

matters and to chart the future course of the Laboratory. The assistance of the Board is also invaluable in improving relationships with entities outside of MIT.

Broad Based Team

The MIT program draws on a wide range of expertise, utilizing faculty and staff members in such departments as mechanical engineering, electrical engineering and computer science, chemical engineering, materials science and engineering, and ocean engineering, as well as in the MIT Center for Policy Alternatives and the Sloan School of Management. Equally important are the experience and perspective provided by representatives of industrial firms associated with cooperative research programs conducted by the Laboratory.

Research work is performed primarily at MIT by faculty, professional staff members, and graduate students under faculty supervision. Special provisions are made in some cases for students to perform part of their research outside MIT under direct supervision of their faculty advisors.

Students receive degrees through their respective academic departments upon completion of degree requirements, which include thesis work done in the Laboratory. Special graduate non-degree programs of continuing education for professionals are arranged through the Center for Advanced Engineering Study of MIT's School of Engineering.

Cooperative Research

The MIT-Industry Polymer Processing Program, which has been in operation since 1973, illustrates the government-industry-university cooperation engendered in the Laboratory. Research in that program is directed towards manufacturing of plastic and rubber products. Unlike the basic polymer industry, which has traditionally had a high research commitment, the polymer processing industry has not been research oriented. In fact, much of the research in the field has been done by the basic polymer industry to support their customers. Thus, the Polymer Processing Program was created to increase activity in an area largely ignored in American universities. In 1973, the National Science Foundation, through its experimental R & D incentives program, awarded seed money to MIT to start the effort. In that year, there were three member companies. NSF seed funding lasted for 5 years and the program is now entirely supported by industry with ten member companies.

The current research program encompasses about 25 projects under the supervision of six faculty members in mechanical engineering, electrical engineering, and chemical engineering. So far 18 patent applications have grown out of program efforts and six patents have been issued. All the sponsors have royalty-free, irrevocable, non-exclusive license to use any technoloby developed during their period of sponsorship. The sponsors do not have rights to patents developed during periods prior or subsequent to their membership. If patents are licensed outside the program, the royalty income is shared among MIT and the sponsors according to a formula.

Group Funding Feasible

The program's budget is now about $650,000 a year, funded entirely by membership fees from the ten companies. This represents a large financial commitment compared to some other university research programs, but that large commitment is justified by the program's results.

Guidance from the sponsors is critical to success and is a great motivator for the graduate students working on projects. With such guidance, the students sense that the work they are doing is valuable and that their results will be put to use. They have a more immediate sense of motivation than with more distant sponsors. To assure such interaction, sponsor representatives visit MIT quarterly for a formal 2-day meeting. At that time, all research projects in the program are reviewed with the students giving presentations in a formal technical conference format. Following each student's presentation, the most closely interested person from the most closely interested sponsor reviews the direction and anticipated value of the project.

Initially, MIT perceived that all communications would have to flow from MIT to the sponsors in order to protect proprietary interests. It became readily apparent, however, that to understand the real issues enough to define basic underlying problems, MIT must get a certain amount of information from the sponsors, who judge just how much they can reveal.

Mutual Benefits Felt

All projects result from suggestions made by the sponsors, but project selection isn't a simple matter of picking things off a list. Topics must be examined closely and often redefined to insure that they are of long-range interest to the sponsor and of academic value to the student.

When a new process is invented, it is not discussed publicly until appropriate lead time has passed and appropriate patent applications are obtained for the sponsors. This is not a significant limitation in university research. The primary difficulty is that potential new sponsors cannot learn about current work. The lead time associated with preparing Ph.D. theses and publications is long enough that the responsibilities to the sponsors can be met without compromising academic freedom.

The fact that this program is in its eighth year testified to the value the sponsors place on it. Benefits that sponsors cite include access to innovative process and product concepts developed during the program, creative stimulation of their own technical personnel, the opportunity to learn from the other member companies, and recruiting opportunities. These benefits are realized from other programs conducted by the Laboratory for Manufacturing and Productivity.

MERTON C. FLEMING is Director of MIT's Materials Processing Center, being appointed in 1979. A professor of metallurgy at MIT since 1969, he was associate professor from 1961 and assistant professor from 1956, when he came to MIT. From 1954 to 1956 he worked as a metallurgist on solidification processing at Abex Corporation. He was selected Abex Professor of Metallurgy at MIT in 1970, Ford Professor of Engineering in 1975, and was elected to the National Academy of Engineers in 1976. He received his S.B. in Metallurgy at MIT in 1951, his S.M. in Metallurgy at MIT in 1952, and his Sc.D. in Metallurgy at MIT in 1954. A member of AIME and the American Foundry Association, he has published extensively in the field of metallurgy.

No Photo Available

GEORGE B. KENNEY is Assistant Director at the Materials Processing Center at MIT, where he handles administrative affairs while conducting Materials Systems Analysis research. A member of ASM, he has worked at the Charles Stark Draper Laboratories, an affiliate of MIT, where he conducted materials testing and qualification of guidance systems work for the Apollo mission. He received his S.B. in Metallurgy and Materials Science at MIT in 1975, also his S.M. in Materials Science at MIT in 1975, and his Sc.D. in Materials Engineering at MIT in 1979.

No Photo Available

MIT Materials Processing Center Diverse

This article could begin: Recent research indicates that the growth of silicon crystals in a magnetic field will produce improved semiconductor chips with significantly higher integrated circuit yields.

Or it could start: Computer control of arc welding processes that will improve production efficiency and weld quality through on-line control and monitoring is now being perfected.

With little apparent relationship, these two important manufacturing technology developments represent the breadth of research now under way at MIT's Materials Processing Center. Research and educational programs at this recently established center are already advancing manufacturing technology in the materials area.

Concept Further Developed

Inaugurated in February, 1980, the Center is pursuing activities that encompass all engineering materials. These activities cover a broad range of materials processing studies from the fundamental to the applied. Many of these programs stress close industrial interaction. Current research at the Center emphasizes innovations to improve performance and productivity and to reduce production costs and energy use.

Specific research goals are to:

- Contribute to the solution of complex materials processing problems.
- Develop an expanded talent base.
- Facilitate technology transfer.
- Strengthen relationships between MIT, industry, and government.

To enhance their capability to assist industry, the Center hopes to establish a Center-Industry Collegium during the coming year. When established, the Collegium will promote innovative research and development programs and encourage information and personnel exchange with industry.

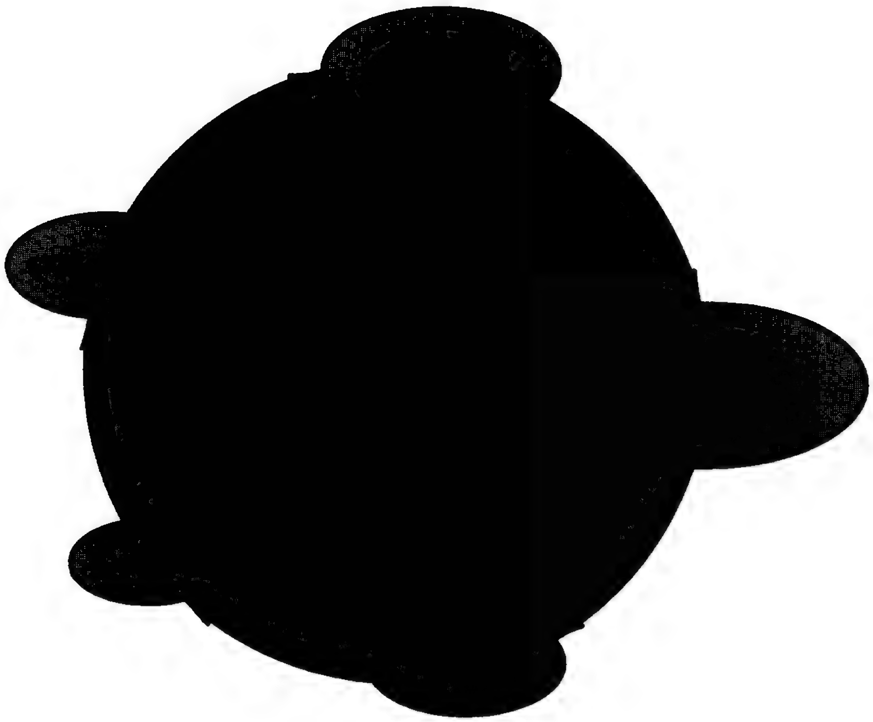


Figure 1

Covers Broad Scope

As they tackle "materials processing" problems, what exactly are the Center's concerns? What is meant by materials processing?

Materials processing covers the transition or "action" stages of the well-known "materials cycle", as seen in Figure 1. These stages are extraction, processing into bulk materials, processing into engineering materials, fabrication, recycling, and disposal. Center programs may address any of these areas.

In materials processing, engineers seek to control the structure, shape and properties of materials in a cost effective and socially aware manner. As the heart of the broader field of materials science and engineering, materials processing links basic science to societal need and experience. This relationship is shown in Figure 2.

Historical Perspective

However, long before men even dreamed of materials science, materials processing was an essential part of society, practiced by skilled artisans who sought to improve both the utility and aesthetic appeal of the materials they used.

Among these materials processing pioneers are those who created the pottery, textiles, and cast arts of Asia Minor as much as 5,000 years ago; the makers of beautiful and functional Japanese swords; medieval iron makers; and the ubiquitous American blacksmith. There are, of course, many others.

The work of these artisans, which relied solely on empirical knowledge, is best described as "materials craftsmanship". Although they obtained desired properties and performance, they did so without the basic science and understanding applied in modern processing and without the modern concept that we can control properties and performance by controlling structure. When this concept was grasped, materials processing became a science and a rapid and continuous expansion in the applications and capabilities of many materials was launched.

Today, the crucial role of structural control at all levels (submicroscopic, microscopic, and macroscopic) is well understood, as are materials processing's essential links to the scientific base and to societal needs. Largely as a result of this understanding, materials processing technology is now critical to national needs. For example, materials processing is central to developing and economically producing sophisticated new materials related to energy, transportation, electronics, and aerospace technology. It is also central to improved productivity and to enhanced energy conversation, recycling processes, environmental protection, and worker health and safety. The need for continuing advanced research is obvious. The Center for Materials Processing was established to help meet this need.

Funding Exceeds $2.5 Million

At present, some 25 affiliated faculty and staff members and 60 graduate students are actively engaged in the Center's research programs. Funding for Center activities, coming from government and industry, exceeds $2.25 million annually. Approximately 20 percent of this money comes from DOD, 33 percent from NASA, 20 percent from industry, and the remainder from MIT and other governmental agencies. To provide its broad range of coverage, the Center is interdepartmental—present faculty and staff members come from the Departments of Materials Science and Engineering, Chemical Engineering, Mechanical Engineering, and Aeronautical Engineering.

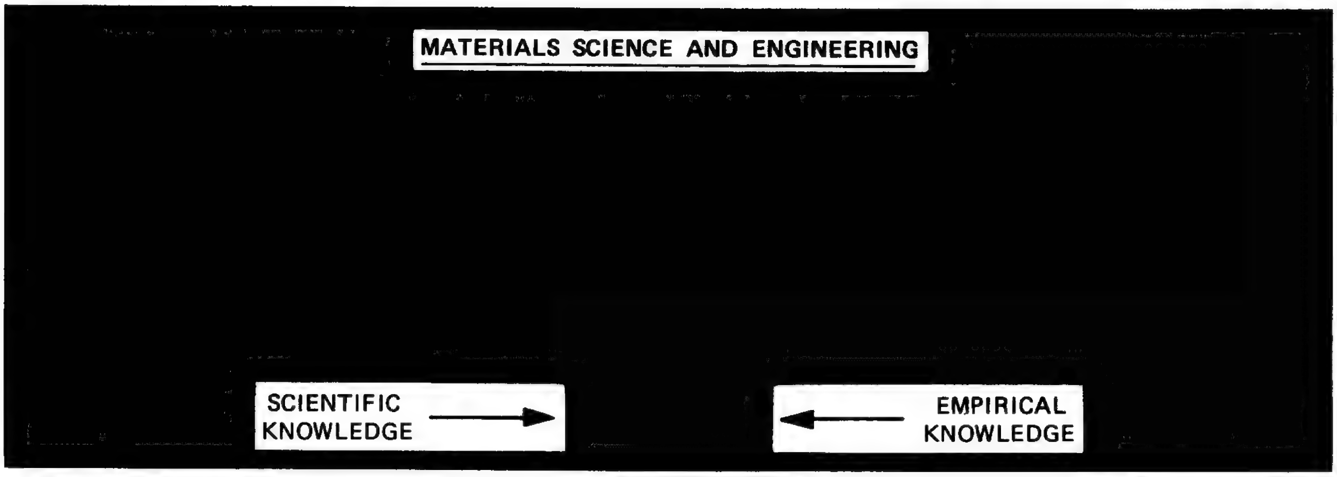


Figure 2

The Center is geared toward interaction with industry and government to develop, extend, and apply the scientific and technological base and broaden the educational base of materials processing. Beyond its broad range of on-going research activities, the Center is also developing new curricula, seminars, and continuing education programs. To help expand its horizons, the Center encourages and sponsors specialized research and academic appointments, including the extended residence at MIT of industry and government personnel as visiting faculty, adjunct faculty, and postdoctoral researchers.

Research at the Center is now directed toward:

- Process innovation and development of new materials through processing
- Mathematical and experimental modeling of processes
- Computer aided processing
- Economic issues relating to materials processing.

Let's consider examples that illustrate on-going research in two of these areas.

BETTER CRYSTAL MATERIALS

In the area of process innovation, Professor August F. Witt is seeking to improve the properties of silicon semiconductors by improving the homogeneity of the single crystal substrate. One method of doing this is to grow the single crystal (from the melt) in a magnetic field. Professor Witt's extensive investigation into the possibilities of this approach has grown out of earlier efforts at MIT and current developments in Japan.

It is well known that crossing a magnetic field with an electrical current can provide vigorous electromagnetic stirring of a liquid melt. Less widely recognized is that the application of a steady DC magnetic field in the absence of an electric current is a powerful method to reduce (and essentially eliminate) convection. This reduction of convection can have significant commercial utility in microelectronics.

The microelectronics industry has grown rapidly as semiconductor designers have found ways to get more and more circuits onto small silicon chips. However, a barrier to further progress is the fact that today's

crystals often have microscopic voids that limit the number of circuits that can be packed on. Thus, improved crystal processing techniques are needed.

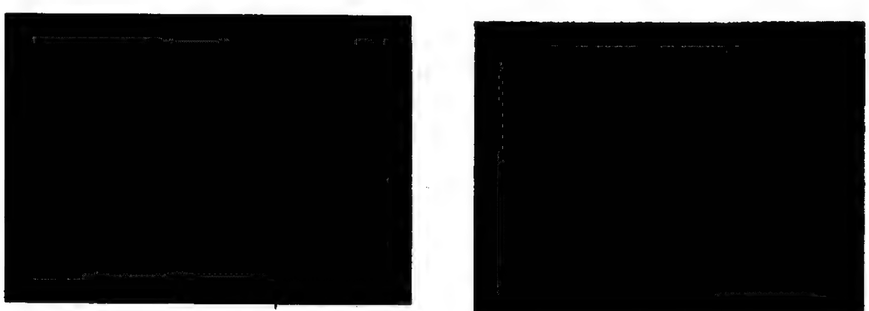
Drawing on work for which MIT researchers received a patent in 1969, Sony in Japan has reportedly perfected a method of growing better silicon crystals under the influence of a magnetic field. Sony claims that such crystals have improved integrated circuit yields by up to 20 percent. The crystals have much greater homogeneity, making them less prone to warping in the course of the circuit etching process.

The dramatic effect of the magnetic field on homogeneity is shown in Figure 3. Turbulent Convection during normal processing results in temperature oscillations that produce a fluctuating growth rate and solute "bands" as shown. The application of a magnetic field strongly damps convection and growth fluctuations. As a result, the single crystals are far more homogeneous and free of banding.

Professor Witt, who had pioneered the original work in this area (which was dismissed by the semiconductor community at that time), is now trying to develop the process for use here. He feels this process will not only yield an improved silicon material but will also reduce the cost of semiconductor production. He is, however, worried about the competitive implications of the Sony development. With the Japanese already well ahead of the U. S. in certain crystal growing techniques, early development of the magnetic process could widen their margin. Nonetheless, Professor Witt's on-going work is much more than "catch up" with the Japanese and we can hope to see commercial application of the magnetic growth technique in the U. S. in the near future.

AUTOMATED ARC WELDING

A second example, illustrating activities in computer aided processing, is the work of Professor Thomas W. Eagar on adaptive control of arc welding. In its varied forms, arc welding is essential to a majority of fabricated structures. Arc welds are often made in an unfavorable environment for the operator and may require consider-



MAGNET ON (1750 GAUSS)

Figure 3

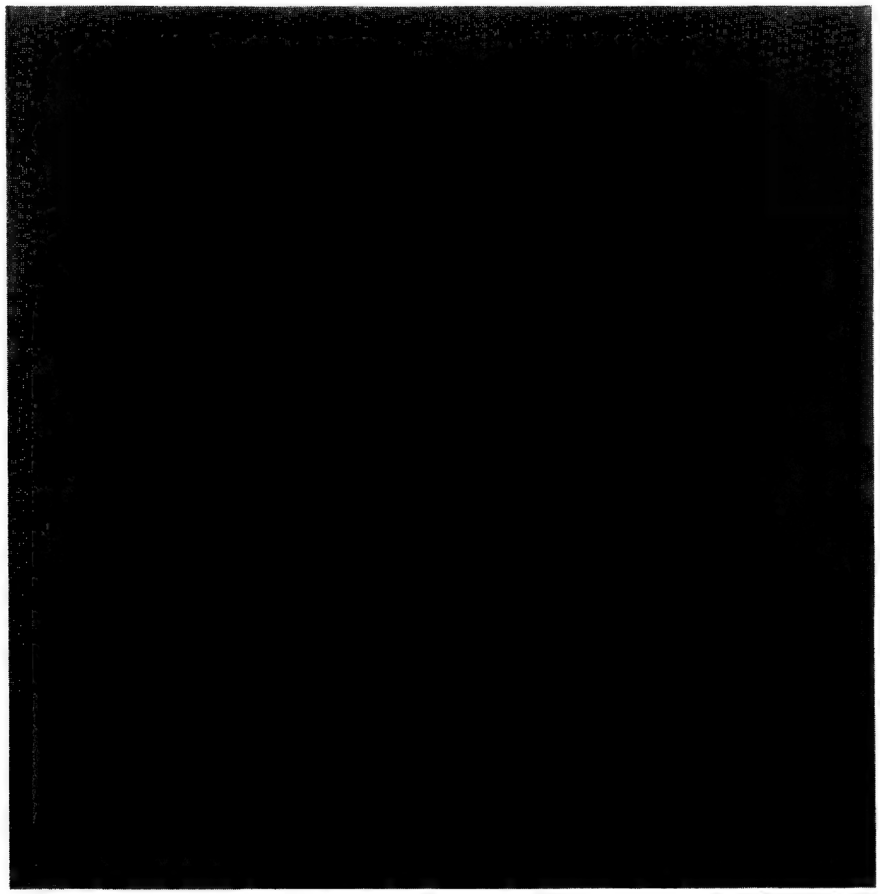


Figure 4

able skill. For these reasons, there is a strong incentive to automate the process. Unfortunately, few reliable on-line sensors have yet been developed. Professor Eagar is now perfecting monitoring techniques that measure voltage fluctuations.

These techniques are based on the fact that the welding arc plasma itself is a unique sensor responding in microseconds to changes in both composition and geometry of a weld. Compositional changes, occurring through a change in shielding gas or by vaporization by the metal pool, distort the plasma's conductivity to cause voltage fluctuations. Similarly, changes in the size or shape of the plasma due to external gas flows or to movements or discontinuities in the base plate also cause voltage fluctuations.

In the work now in progress in Professor Eagar's laboratory, welding discontinuities as small as 1/16th of an inch have been detected by measuring the voltage fluctuations. Improved resolution is expected with the application of computer aided signal analysis.

Some examples of this work are illustrated in Figures 4 and 5. Figure 4 shows the welding voltage signals for good and bad welds. Bad welds in this case are steel welds with 1/8 or 1/16

Figure 5

inch of copper alloy contamination on the surface. The real-time voltage variations between good and bad welds are not perceptible. However, when transformed to the frequency domain, as shown in Figure 5, the differences are much more pronounced in both the real and imaginary component.

In continuing work, computer aided voltage monitoring techniques such as this are being perfected. The goal is to develop on-line computer control and monitoring techniques that will assure the production of uniform, high-quality, defect-free welds. With the widespread use of arc welding in manufacturing processes, the significance of this research is very far-reaching.

Improving Interaction With Industry

As a further step forward, the Center hopes within the coming year to initiate a Center-Industry Collegium—a partnership to promote innovative research and development programs and enhance information and personnel exchange activities. The Collegium should help industry to profit from MIT research in materials processing, while also promoting benefits to MIT through improved industrial interaction. Through this Collegium, the Center plans to establish formal mechanisms for information exchange. These will include a number of research briefings at MIT, periodic mailings of research results to member companies, and development of special joint research activities. Plans for development of the Collegium are well under way. Through the Collegium and the continuing research and educational activities of faculty and staff members, the Center should make significant contributions to technological leadership in materials processing.

Potential Savings of $20,000 Per Engine

Isothermal Forging of Engine Parts

BRYANT H. WALKER is a Materials Project Engineer, Materials and Mechanics Technology, of the Government Product Division of Pratt and Whitney Aircraft Group. He is supervisor of the Materials Forming and Fabrication Research and Development Group responsible for development and implementation of GATORIZING and ceramic technologies. He directs the efforts of a group of senior engineers, technicians, and facilities in performing material and process development. From 1972 to 1976 he was supervisor of a new technology group developing isothermal forging of alloys in a temporary superplastic state. From 1970 to 1972 he was responsible for investigating and implementing use of fracture mechanics and acoustic emmission for application to life prediction of gas turbine components, and for generating materials capability curves for various alloys in high pressure gaseous environments for application to space shuttle rocket engine designs. He received a B.S.E. in Materials Science from the University of South Florida (1969) and an M.S.E. in Materials from the University of South Florida (1973). Mr. Walker is an active member of A.S.M.E. and serves on its Gas Turbine Division Structural Ceramics Committee and its Manufacturing, Materials, and Metallurgy Committee. He is the holder of several patents and is author of over a dozen papers.

No Photo Available

LARRY N. FUSS is a Senior Materials Test Engineer, Government Products Division, of Pratt and Whitney Aircraft Group. He is responsible to the Superplastic Forming and Fabrication Research Group for planning and conducting development programs for extending GATORIZING (isothermal forging) techniques. He has been the responsible engineer on near net shape forging programs for F100 engine disks and programs for the production of integrally bladed rotors. He is also responsible for material behavior investigations as applied to isothermal forging. Earlier, he had worked on the analysis of raw material test data including tensile, stress rupture and fatigue, resulting in statistically based material capability curves. Also, improving design analysis computing techniques. He received a B.S. in Mechanical Engineering from Colorado State University in 1970. He has authored a book, 'Manufacturing Process for the Production of Near Net Superalloy Disk Shapes by Isothermal Forging.'

No Photo Available

The application of isothermal techniques in recent years has significantly advanced forging technology and capabilities. Forgers now can form complex parts practically to design shape, eliminating costly machining operations and allowing very significant material savings.

As a prime example, Pratt and Whitney Aircraft has applied its GATORIZING® forging process to rotating parts of the F100 aircraft engine. In a recently completed study of several subscale parts and a full scale turbine disk, they demonstrated the capability to isothermally forge parts to within at least 0.050 inch of design dimensions.

A cost analysis of the results indicated that isothermal forging will reduce consumption of critical materials by about 50 percent and reduce manufacturing costs on each engine by as much as $20,000. Furthermore, mechanical properties of the forged disks at least equaled and generally exceeded those of previously produced forged material. Improvements in creep, stress rupture, and low cycle fatigue properties were particularly significant. All mechanical properties significantly exceeded production specifications for the material. Finally, isothermal forgings are particularly adaptable to nondestructive testing, and techniques were developed as part of this effort.

Two Step Process

Pratt and Whitney has been using their two step isothermal forging process to produce turbine parts for nearly 11 years. Application to the F100 engine was investigated in a manufacturing technology program, anticipating the potential cost payoff. In the first forging step, a preform is produced that can be easily forged to a near net shape, lap free part in a second step. The preform is designed for inspection by sonic techniques.

GATORIZING® uses hot isothermal forging and a controlled forging rate to either produce or maintain a superplastic condition in the forged material. By exploiting this superplastic state, the fabricator can forge complex, contoured shapes to extremely close tolerance with no surface cracking. Advantages over other forging techniques are many:

- The flat, pancake like preform can be forged easily and rapidly in a small hydraulic press (500 tons) using flat dies.
- Sonic inspection of the preform is thorough and reliable, presenting no blind zones as with cylindrical billets.
- Material distribution resulting from the preform step allows final forging of complex shapes without forging overlaps.
- Efficient heat treatment of the forging shapes results in mechanical properties that are superior to those of the thicker section forgings of the previous one step GATORIZING® process.
- Manufacturing costs are reduced because less input weight and far fewer man-hours are required for finish machining.

The F100 manufacturing technology program was a three phase, 21 month effort covering six parts—four turbine disks, a compressor cone seal, and the turbine rim spacer—fabricated from IN-100 alloy. The beginning phase consisted of subscale die design, forging studies on subscale parts, and evaluation of these parts. In the second phase, full scale turbine disks were produced for laboratory evaluation and experimental engine testing. The third phase was directed toward establishing acceptable nondestructive inspection procedures and conducting an indepth cost analysis, which also covered projections for three compressor disks not included in the forging studies.

Subscale Forging Studies

In the subscale phase of the program, the preform and final forging shapes were optimized through iterative forging studies. The subscale approach provided obvious savings in die manufacture and modification during this iterative study. Furthermore, experience gained from previous subscale to full scale studies had proven the validity of subscale results.

Forging iterations were conducted using flat, pancake like IN-100 preforms of constant volume and varying diameter. The results of these forging trials indicated where more or less material was required for optimum final die fill. The subscale preforms were machined rather than forged to provide geometry flexibility without high tooling costs. The final forging iterations were conducted in a 500 ton vacuum press at 1950 to 2000 F with a controlled forging rate of 0.1 min—1. Forging loads were restricted to accurately reflect the unit force available from the 1650 ton press that would be used for final forging of full scale parts.

Dimensions from the full scale configurations were scaled by one third for the subscale die designs. The subscale dies were fabricated from 8 inch diameter by 4 inch TZM molybdenum blocks. The forging configuration design effort for each of the parts was directed toward minimizing the forging input weight by using, where possible, a 0.050 inch forging envelope around each part. This was done while keeping in mind forgeability and sonic inspection capability. Figure 1 shows the near net shape envelope and the current forging shape relative to the final shape of a turbine disk.

After an optimum preform and final forging configuration were established, additional subscale forgings were made for each part to demonstrate reproducibility of the process. These forgings were used for dimensional stability studies and metallographic examination.

Lapping, Die Fill Present Problems

To illustrate these subscale forging studies, consider the effort on the second stage turbine disk. Attempts to optimize the preform configuration began with a 5.940 inch diameter preform—very close to the maximum diameter of the actual part. Die fill during forging of this preform was good, but laps were found in the bore and the hub sections of the part. These laps apparently formed as follows.

Near the end of the forging stroke, the rim and hub sections of the disk were completely filled, but the bore section was not, as shown in Figure 2. As the die continued to close, material in the hub section was forced toward the web and the bore, while material in the rim was forced radially inward. The opposing flows met where the bore cavity was filling and the material folded on itself, forming the lap.

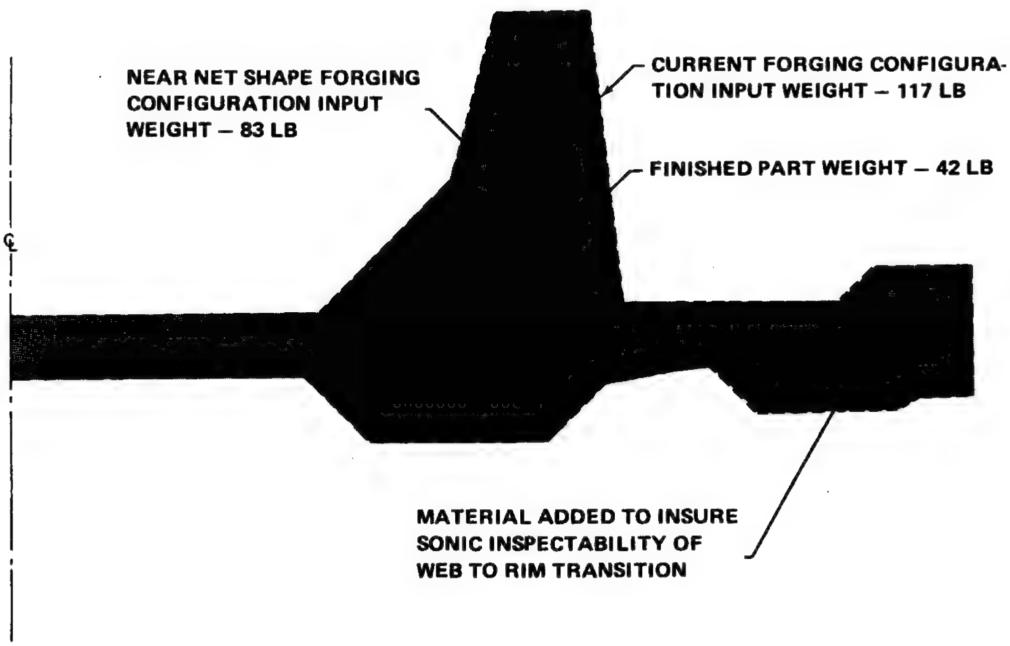


Figure 1

To compensate, a smaller diameter preform—5.000 inch—was tried. The idea was to eliminate inward radial movement and increase outward radial movement, thereby decreasing the possibility of lap formation. However, using this preform, the rim areas of the die cavity did not fill. Measurements of this part showed that die travel was severely limited by material trapped in the center section of the part.

Optimum Preform Found

Experience gained during development of a similar part showed that a hole placed in the center of a preform can prevent such entrapment. The hole allows material to move radially inward or outward in the center section. To overcome the problems being encountered in forging the subscale disk, such a hole was added and the die contour was modified to increase the radius at the interior of the hub section and prevent lapping.

Two more preforms were machined with a 0.75 inch hole placed in the center. One preform had a 4.8 inch diameter and the other a 5.00 inch diameter. The forging made from the 4.8 inch diameter preform was lap free, but die fill was incomplete at the rim of the part.

However, the 5.00 inch diameter preform yielded an excellent forging. There were no indications of lapping, even with examination of cross sections, and the die cavity was well filled. Additional forgings from this preform configuration were also well defined, indicating that this was the optimum preform needed.

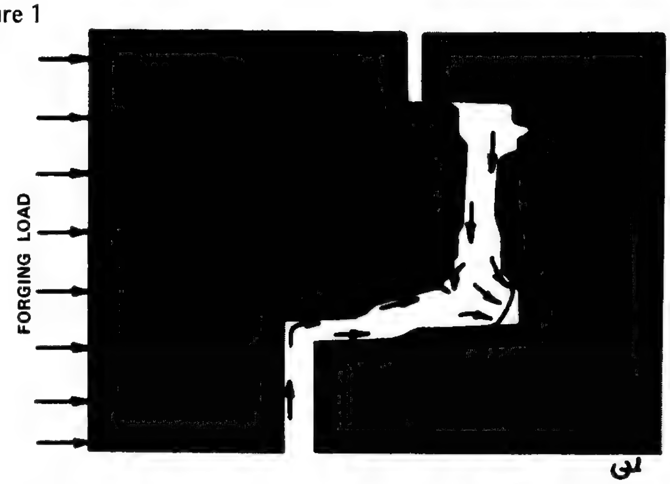


Figure 2

Subscale studies for the other five parts were conductec in a similar manner. Metallographic examinations of heat treated and sectioned forgings showed homogeneous microstructures, no abnormalities, and conformance tc specification.

Full Scale Forging

A full scale forging study was conducted on the first stage turbine disk. Designs were initially based on the subscale forging configuration. Full scale dies were fabricated and the process was modified until an optimum full scale preform and forging configuration were found.

Following this, a heat treat study was conducted to examine dimensional stability of the configuration and mechanical property testing was undertaken to qualify the process.

Forging dies were fabricated from 24 inch TZM molybdenum blocks. Figure 3 shows the completed die set. Blocks were pinned around the upper circumference of the die cavity as guides to engage the punch with the die early in the forging stroke and minimize eccentric material flow.

In the preform step, IN-100 billets, all machined from 6.2 inch diameter forging stock, were isothermally forged on flat dies in a 500 ton press to the pancake like configuration. Forging was done at 2000 F and a strain rate of 0.15 min—1. A centering dimple was machined on one side of each preform to match a male locator on the knockout head of the lower die.

Preform Size Adjusted

All final forgings were made in a 1650 ton hydraulic press. The subscale study for these disks indicated that preforms ranging from 4.6 to 5.5 inch diameter would yield lap free, well defined final forgings. Based on this result, the first full scale preform was forged to a 15 inch diameter and weighed 83 pounds.

Using this preform in final forging, the integral arm cavity of the die did not fill completely. A well defined rim and abundance of flash on the part indicated that the preform diameter was too large and that incomplete die fill was caused by improper material distribution in the preform. Measurements of the forgings indicated that a restrike would not fill the integral arm cavity. Thus, a 14 inch diameter preform was selected for the next iteration.

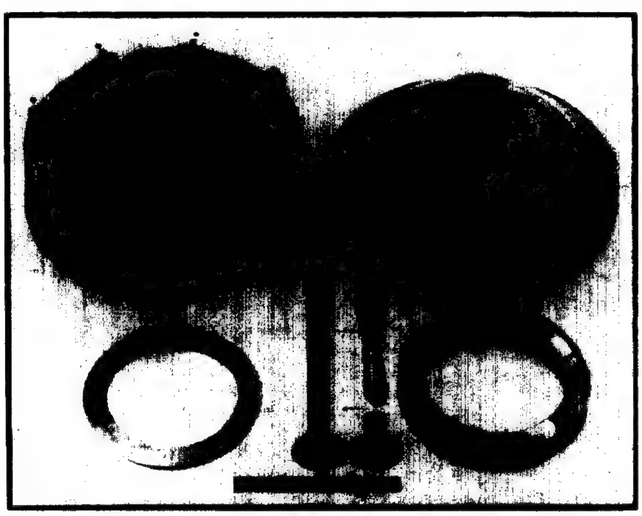


Figure 3

Forging of this smaller diameter preform resulted in an excellent part. The die cavity was well filled and there was symmetrical flash at the rim. Figures 4 and 5 show the excellent detail that was achieved with this forging. Subscale forgings are also shown.

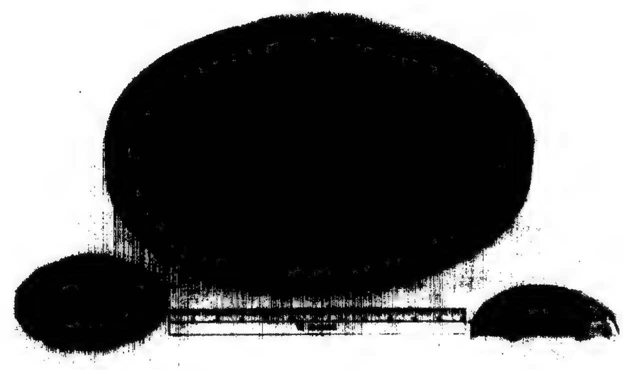


Figure 4

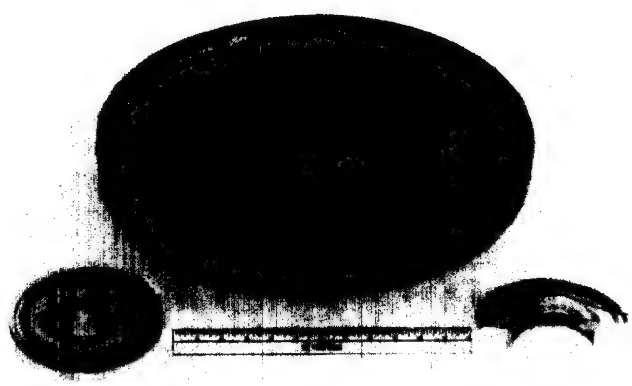


Figure 5

Distortion Encountered

Two full scale forgings were heat treated in accordance with Pratt and Whitney's specification for the part. Following the solution cycle (2 hours at 2065 F followed by an oil quench), measurements indicated that both

forgings were distorted—the hub having moved down approximately 0.150 inch relative to the rim.

When the heat treatment was completed, additional measurements indicated no change in this distortion. Because of the distortion, the forgings could not be finish machined into a final part.

This distortion appeared to be nothing more than the forging sagging under its own weight. The fact that the IN—100 material is superplastic at 2065 F supports this explanation. Conventional forging shapes are quite bulky, so the sagging phenomenon either was not noticed or did not occur in the past. The isothermal forgings have a much thinner cross section and therefore are more vulnerable to distortion.

The distortion problem was solved by adding an inner ring to the heat treat fixture to support the center section of the forging, as shown in Figure 6. This proved successful and subsequent heat treated forgings showed no relative movement between the hub and rim.

Shrinkage Detected

However, the heat treating study revealed another problem. Postheat treat measurements showed that the forgings were shrinking, both radially and axially, due to cystallographic changes in the material. The radial shrinkage was much greater, amounting to approximately 0.050 inch on the outer diameter of the forging. This shrinkage occurred during the solution cycle and did not increase during the precipitation and aging cycles. The forging tool was modified to account for the radial shrinkage by increasing several outside diameters.

To demonstrate process reproducibility, four additional forgings were made. The various process modifications proved successful and these forgings were qualified for finish machining. One forging was finish machined to the current part print and met all qualifications.

Mechanical Properties Improved

To evaluate mechanical properties, tensile, creep, and combination stress rupture specimens were machined from the disk forging in bore, spacer, web, and rim locations. Low cycle fatigue specimens were also machined from the rim. To approximate engine operating conditions, the fatigue specimens were tested at 1000 and 1200 F at the total strain range of 1.0 percent. These conditions were also selected because substantial production data for statistical comparisons already existed.

A thorough comparison was made between properties of the isothermal forgings and those for current production

Figure 6

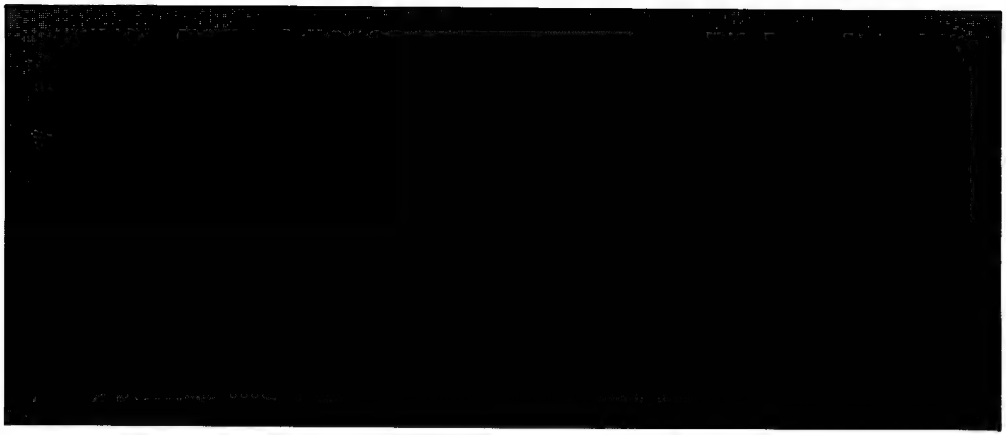
items. The current production properties represent many IN—100 parts from many heats of material and several vendor sources.

The isothermal near net shape forgings showed significantly improved creep, stress rupture, and low cycle fatigue properties. The 0.1 and 0.2 percent creep properties were up 32 and 38 percent, respectively, compared with production parts. For stress rupture properties, the near net shape average exceeded the current production average by 28.5 percent. Low cycle fatigue life for the isothermal forgings was 10 percent higher at 1000 F and 140 percent higher at 1200 F. Although additional testing is necessary to increase confidence in these results, a significant improvement in fatigue life is clearly indicated.

The tensile properties of the isothermal forgings compared favorably with those of production material. The average results were the same or slightly better.

Based on t-tests at a 95 percent confidence level, the improvements for creep at 0.2 percent and low cycle fatigue at 1000 F were found to be statistically significant. Although the other properties showed improvement, more testing is necessary to demonstrate statistical significance.

Process qualification also included low cycle fatigue testing of bolthole specimens. These tests were run at 10 cpm and at 1000 and 1200 F with a stress level of 110 ksi. Again, excellent results were obtained. The isothermally forged NNS parts showed a 335 percent improvement in properties at 1000 F and a 165 percent improvement at 1200 F when compared with current production items.



*The near net shape process uses the center slug material from the 1-2 turbine rim spacer forging.

Table 1

Further comparison of the results shows that the near net shape material has superior crack initiation life, while the crack propagation life remained unchanged.

Sonic Inspection Demonstrated

To demonstrate that the forgings can be inspected using sonic techniques, Pratt and Whitney used a sonic reference master disk. This reference master was skin cut and then drilled with flat bottom holes at 36 locations. Instrumentation and an advanced transducer were then developed for testing all 36 targets in a single setup in both 'A' and 'C' scan modes. The success of the demonstration indicates that under controlled conditions, near net shape forgings similar to this demonstration disk can be inspected to a No. 1 flat bottom hole acceptance limit. Detection of these targets required near surface resolution to 0.050 inch and similar far surface resolution through 3.25 inches of material.

The equipment used for sonic inspection included a high-rise time pulser and a broadband receiver coupled with a new commercially available, highly damped, lead-metaniobate transducer. The focal characteristics of the transducer provided sufficient beam spread to detect the demonstration disk targets opposite adjacent steps and edges.

Applying the knowledge gained in inspecting the demonstration disk, Pratt and Whitney reviewed the preliminary forging designs for the other parts selected for this program and recommended changes that will improve inspectability and eliminate sonic blind zones.

Cost Improvements

Economic analysis indicated a savings of $20,000 per F100 engine with the incorporation of isothermal forging into production. This significant savings would result from using the two step forging process on all the IN-100 rotating parts—three compressor disks, a cone seal, four turbine disks, and the turbine rim spacer.

The $20,000 savings includes $7,200 in materials savings (444 pounds less material per engine) and $800 reduction in machining costs, and $12,000 from inhouse production of the nine rotating parts.

Table 1 shows the near net shape input weights compared with production input weights for the six parts forged in the subscale study. The full scale input weights are based on the optimized subscale configurations. For these six parts, the total weight savings is 223 pounds.

Significant input weight savings were demonstrated also in a recently completed IR&D program for the composite near net shape forging of the three compressor disks. These bring the total input weight savings to 444 pounds.

Detailed analysis of the production costs of the full scale turbine disk revealed a net savings of $740 per finished disk. This savings, and those projected for the other parts, are possible despite the extra forging step in the two step process.

Work on these engine parts has demonstrated that the two step isothermal forging process can be adapted to a variety of forging shapes. Optimum material distribution in the preform, obtained simply by varying the diameter of the pancake, allows production of lap free, complex forgings. A subscale approach to process optimization appears valid based on results of this effort.

INDEX BY TOPIC

Note: The following index entries refer to articles appearing in Vol. 4, Nos. 3 and 4 and Vol. 5, Nos. 1—4. Previous articles were indexed in Vol. 4, No. 2.

A-10 AIRCRAFT; Vol. 5, No. 3, p. 14
ABL (ALLEGHENY BALLISTICS LABS); Vol. 5, No. 4, p. 46
ACOUSTIC TESTING; Vol. 4, No. 3, p: 35
ADCONS (Analog To Digital Converter); Vol. 5, No. 4, p. 30
AEGIS (Navy Missile System); Vol. 4, No. 3, p. 12
AFATL (Air Force Armament Test Laboratory); Vol. 5, No. 3 p. 14
Airfoils; Vol. 5, No. 1, p. 40
Aircraft Engines; Vol. 5, No. 3 p. 28; Vol. 5, No. 3, p. 33
AIRS (Accident Information Retrieval Systems); Vol. 4, No. 4 p. 3; Vol. 5, No. 1, p. 3
ALEXTR Computer Program; Vol. 5, No. 2, p. 18
Alumina; Vol. 4, No. 3, p. 13
Aluminum; Vol. 4, No. 3, p. 7; Vol. 4, No. 4, p. 18; Vol. 4, No. 4, p. 22; Vol. 5, No. 2, p. 11; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 28; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21
AMMRC (Army Materials and Mechanics Research Center)
AMMRC (Army Materials and Mechanics Research Center); Vol. 5, No. 2, p. 18
Ammunition Manufacturing; Vol. 4, No. 4, p. 15; Vol. 5, No. 2, p. 33
AMPBMA (Army Munitions Production Base Modernization Agency); Vol. 5, No. 3, p. 22; Vol. 5, No. 3, p. 26
AN—TPQ37 (Army Firefinder Radar); Vol. 4, No. 3, p. 12
APT (Automatically Programmed Tool) System; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 24
ARCADENE 360 Propellant; Vol. 4, No. 4, p. 24
ARMCOM (U.S. Army Armament Command); Vol. 4, No. 4, p. 20
ARRADCOM (U.S. Army Armament Research and Development Command); Vol. 5, No. 2, p. 18; Vol. %, No. 3, p. 3; Vol. 5 No. 4, p. 46
ARRCOM (U.S. Army Armament Readiness Command); Vol. 4, No. 4, p. 15
Automated Processing; Vol. 4, No. 4, p. 3; Vol. 4, No. 4, p. 24; Vol. 5, No. 2, p. 45
AVRADCOM (Army Aviation Research and Development Command);Vol. 5, No. 1, p. 3; Vol. 5, No. 3, p. 18; Vol. 5, No. 3, p. 42; Vol. 5, No. 4, p. 50
B-1 Aircraft; Vol. 5, No. 3, p. 42
Ballistic Tests; Vol. 5, No. 3, p. 14
Black Hawk Helicopters; Vol. 4, No. 4, p. 3; Vol. 5, No. 1, p. 3
BLDFORG Computer Program; Vol. 5, No. 2, p. 18
BLDSURF Computer Program; Vol. 5, No. 2, p. 18
Brass; Vol. 5, No. 2, p. 11
Cannon Tubes; Vol. 5, No. 2, p. 7; Vol. 5, No. 2, p. 42; Vol. 5, No. 2, p. 45; Vol. 5, No. 4, p. 40
Casting; Vol. 4, No. 4, p. 45; Vol. 5, No. 1, p. 35; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 14; Vol. 5, No. 3, p. 26; Vol. 5, No. 3, p. 28
CCI (Center Core Igniter); Vol. 5, No. 4, p. 46; Vol. 5, No. 4, p. 50
Ceramic Materials; Vol. 4, No. 3, p. 12; Vol. 4, No. 4, p. 45
Checkweigher Scales; Vol. 5, No. 4, p. 30
Chemical Milling; Vol. 5, No. 3, p. 28
CMOS (Complimentary Metal Oxide Semiconductor); Vol. 5, No. 4, p. 3
Coatings; Vol. 5, No. 3, p. 38; Vol. 5, No. 4, p. 12
Cobalt; Vol. 5, No. 3, p. 11
Cold Forming; Vol. 4, No. 4, p. 16
Cold Isostatic Pressing; Vol. 5, No. 3, p. 14
Colt Rifles; vol. 4, No. 4, p. 15
Composites; Vol. 4, No. 3, p. 29; Vol. 5, No. 4, p. 21
Compressor Blades; Vol. 5, No. 1, p. 40; Vol. 5, No. 2, p. 18; Vol. 5 No. 3, p. 33
Compressor Components; Vol. 5, No. 2, p. 3
Computer-Aided Design (CAD); Vol. 4, No. 3, p. 3; Vol. 4, No. 3, p. 10; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 24; Vol. 5, No. 3, p. 42; Vol. 5, No. 4, p. 30
Computer-Aided Inspection (CAI); Vol. 4, No. 3, p. 24; Vol. 4, No. 3, p. 37
Computer-Aided Manufacturing (CAM); Vol. 4, No. 3, p. 3; Vol. 5, No. 1, p. 20; Vol. 5, No. 1, p. 30; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 33; Vol. 5, No. 3, p. 42
Computer-Aided Planning (CAP); Vol. 4, No. 4, p. 28
Computer Storage; Vol. 4, No. 4, p. 3
Computerized Production Process Planning (CPPP); Vol. 4, No. 4 p. 29; Vol. 5, No. 1, p. 20
Cooling; Vol. 5, No. 1, p. 35; Vol 5, No. 2, p. 11
Copper; Vol 5, No. 2, p. 11; Vol. 5 No. 2, p. 37
COPPERHEAD System; Vol. 5 No. 4, p. 3
COPPL (Computer Process Planning Language); Vol. 4, No. 4, p. 30
Coradcom (Communications R&D Command); Vol. 5, No. 1, p. 30
Coring Techniques; Vol. 5, No. 1 p. 35
Cost Analysis; Vol. 4, No. 3, p. 5 Vol. 4, No. 3, p. 12; Vol, 4, No 3, p. 29; Vol. 4, No. 4, p. 3 Vol. 5, No. 1, p. 20; Vol. 5, No 1, p. 35; Vol. 5, No. 1, p. 40 Vol. 5, No. 3, p. 3
CSMM (Crash Survivable Memor Module); Vol. 5, No. 1, p. 3
Cylinders; Vol. 5, No. 3, p. 22
DARCOM (U.S. Army Materi Development and Readines Command); Vol. 5, No. 3, p. 4 Vol. 5, No. 4, p. 3; Vol. 5, No. p. 50
Densification; Vol. 5, No. 2, p. 2 Vol. 5, No. 3, p. 28
Diamond Turning; Vol. 5, No. p. 3
Dielectric Constants; Vol. 4, No. p. 16
Dies; Vol. 5, No. 2, p. 3; Vol. No. 2, p. 18; Vol. 5, No. 3, p. Vol. 5, No. 3, p. 26

Diffusion Bonding; Vol. 5, No. 3, p. 42
Diodes; Vol. 5, No. 1, p. 3
Directional Solidification; Vol. 4, No. 4, p. 45
DSP (Drain Source Protected Device); Vol. 4, No. 4, p. 8
DSW (Direct Step Wafer Aligner); Vol. 4, No. 4, p. 13
Electrical Discharge Machining (EDM); Vol. 5, No. 1, p. 35; Vol. 5, No. 2, p. 18
Electromagnetic Interference (EMI); Vol. 5, No. 4, p. 3
Electronic Devices; Vol. 4, No. 4, p. 3; Vol. 5, No. 2, p. 11; Vol. 5, No. 4, p. 36
Engine Frames; Vol. 5, No. 3, p. 28
Engineering Steel; Vol. 4, No. 4, p. 35; Vol. 4, No. 4, p. 38; Vol. 5, No. 1, p. 40;
Vol. 5, No. 2, p. 24
Exothermic Pack Process; Vol. 4, No. 4, p. 45
EXTCAM Computer Program; Vol. 5, No. 2, p. 18
Extrusion(s); Vol. 5, No. 2, p. 18; Vol. 5, No. 3, p. 3
FAE II (Fuel Air Explosive Program 2); Vol. 5, No. 3, p. 22; Vol. 5, No. 3, p. 26
Fan Blades; Vol. %, No. 3, p. 33
Fatigue Tests; Vol. 5, No. 1, p. 35; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 28
FDR (Flight Data Recorder); Vol. 5, No. 1, p. 3
Filament Winding Process; Vol. 4, No. 3, p. 29
Fluorescent Penetrant Inspection (FPI); Vol. 5, No. 3, p. 28
Forging(s); Vol. 4, No. 4, p. 37; Vol. 5, No. 1, p. 40; Vol. 5, No. 1, p. 45; Vol. 5, No. 2, p. 3; Vol. 5, No. 2, p. 7; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 24; Vol. 5, No. 4, p. 40
Fuel Containers; Vol. 5, No. 3, p. 22
Fuse Technology; Vol. 4, No. 4, p. 20; Vol. 5, No. 3, p. 3
Gau-8 Gun; Vol. 5, No. 3, p. 14
Gears; Vol. 4, No. 4, p. 39
Gold; Vol. 4, No. 3, p. 5; Vol. 5, No. 4, p. 12
Gun Barrels; Vol. 4, No. 4, p. 16; Vol. 5, No. 1, p. 45; Vol. 5, No. 2, p. 18; Vol. 5, No. 3, p. 14
Gunpowder; Vol. 5, No. 2, p. 33
Gyro Assemblies; Vol. 5, No. 4, p. 3
Heat Pipes; Vol. 5, No. 2, p. 11
Heat Treating; Vol. 5, No. 3, p. 33; Vol. 5, No. 4, p. 40
HLS (Hellfire Laser Seeker); Vol. 5, No. 4, p. 3
Homogenization; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 28
Hot Die Forging; Vol. 5, No. 2, p. 3
Hot Isostatic Pressing (HIP); Vol. 4, No. 4, p. 41; Vol. 5, No. 1, p. 16; Vol. 5, No. 2 p. 28; Vol. 5, No. 3, p. 28
Hot Rolling; Vol 5, No. 3,p. 11
HTPB (Hydroxy Terminated Polybutadiene); Vol. 4, No. 4, p. 24
Hubs; Vol. 5, No. 3, p. 28
Hybrid Circuits; Vol. 4, No. 3, p. 5; Vol. 4, No. 3, p. 22; Vol. 4, No. 4, p. 3; Vol. 5, No. 1, p. 3; Vol. 5, No. 4, p. 3
Hydrostatic Extrusion; Vol. 5, No. 3, p. 3
Hydrotesting; Vol. 4, No. 3, p. 39
Immersion Coupling; Vol. 5, No. 4, p. 3
Infared Imaging; Vol. 4, No. 3, p. 22
Injection Molding; Vol. 4, No. 4, p. 24; Vol. 5, No. 3, p. 14; Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21;
Investment Casting; Vol. 4, No. 4, p. 19
IPDI (Isophorone Diioxocyanate); Vol. 4, No. 4, p. 24
Iridium; Vol. 4, No. 3, p. 5
Isothermal Forging; Vol. 5, No. 1, p. 40; Vol. 5, No. 3, p. 33
Laminates; Vol. 5, No. 2, p. 37
LAP Plants (Load, Assemble, And Pack Plants); Vol. 5, No. 3, p. 14; Vol. 5, No. 4, p. 30; Vol. 5, No. 4, p. 46; Vol. 5, No. 4, p. 50
Large Scale Integration (LSI); Vol. 4, No. 3, p. 3; Vol. 4, No. 3, p. 10; Vol. 5, No. 4, p. 3
Laser Seekers; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 21
Lathes; Vol. 5, No. 1, p. 30
LOCASERT (Location And Insertion) Device; Vol. 5, No. 4, p. 36
LPCVD (Low Pressure Chemical Vapor Deposition); Vol. 4, No. 4, p. 13
Lubricants; Vol. 5, No. 2, p. 3 Vol. 5, No. 3, p. 33
M16 Rifles; Vol. 4, No. 4, p. 15
Machining; Vol. 5, No. 1, p. 20; Vol. 5, No. 3, p. 3; Vol. 5, No. 4, p. 3
Mann Barrel Tests; Vol. 5, No. 3 p. 14
Manufacturing Technology; Vol. 4, No. 3, p. 10; Vol. 4, No. 3, p. 12; Vol. 4, No. 3, p. 31; Vol. 4, No. 4, p. 3; Vol. 5, No. 3, p. 3 Vol. 5, No. 3, p. 38; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21
Mechanical Properties; Vol. 4, No. 4, p. 43; Vol. 5, No. 2, p. 3; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 33; Vol. 5, No. 4, p. 21; Vol. 5, No. 4, p. 40
MEM (Momentum Exchange Mass); Vol. 4, No. 4, p. 21
Metallization; Vol. 4, No. 3, p. 15
Micom (Army Missile Command); Vol. 4, No. 3, p. 3; Vol. 4, No. 3, p. 5; Vol. 4, No. 3, p. 10; Vol. 4, No. 3, p. 12; Vol. 4, No. 3, p. 22; Vol. 4, No. 3, p. 29; Vol. 4, No. 4, p. 28; Vol. 5, No. 3, p. 38; Vol. 5, No 4, p. 3; Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21; Vol. 5, No. 4, p. 36
Microelectronics; Vol. 4, No. 4, p. 3
Microwave Circuits; Vol. 4, No. 3, p. 12
MIFASS (Marine Integrated Fire And Air Support System); Vol. 4, No. 4, p. 7; Vol. 5, No. 1, p. 3
Military Vehicles; Vol. 4, No. 4, p. 39
Military Weapon Systems; Vol. 4, No. 3, p. 3
Milling; Vol. 4, No. 4, p. 18
Mirrors; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 12
Missile Manufacture; Vol. 5, No. 2, p. 42; Vol. 5, No. 4, p. 3
Missile Seekers; Vol. 5, No. 4, p. 21
Mitigators; Vol. 4, No. 4, p. 23
MNOS BORAM (Metal Nitride Oxide Semiconductor Block Oriented Random Access Memory); Vol. 4, No. 4, p. 3; Vol. 5, No. 1, p. 3
Molding: Vol. 5, No. 3, p. 22; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21
MPIP (Manufacturing Productivity Improvement Program); Vol. 5, No. 4, p. 50
NASTRAN Computer Program; Vol. 4, No. 3, p. 37
Near Net Shape Forming; Vol. 4, No. 4, p. 41; Vol. 5, No. 2, p. 3
Netweigher Scales; Vol. 5, No. 4, p. 30
Nickel; Vol. 4, No. 4, p. 41; Vol. 4, No. 4, p. 48; Vol. 5, No. 1, p. 45; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 11; Vol. 5, No. 3, p. 28; Vol. 5, No. 3, p. 33
NOSING Computer Program; Vol. 5, No. 2, p. 18

Nondestructive Testing; Vol. 4, No. 4, p. 23; Vol. 5, No. 3, p. 28
Numerical Controlled Machining; Vol. 5, No. 1 p. 30; Vol. 5, No. 2, p. 18
Optics; Vol. 5, No. 4, p. 3
Osmium; Vol. 4, No. 3, p. 5
Packaging; Vol. 4, No. 3, p. 8
Palladium; Vol. 4, No. 3, p. 5
Peel Strength Tests; Vol. 5, No. 2, p. 37
Phase Shifters; Vol. 4, No. 3, p. 12
Phased Array Antennas; Vol. 4, No. 3, p. 12
Photoimaging; Vol. 4, No. 4, p. 13
Pinions; Vol. 5, No. 3, p. 3
Plasma Arc Heating; Vol. 5, No. 1, p. 16
Plastics; Vol. 5, No. 3, p. 38;

Plastics; Vol. 5, No. 3, p. 38;
Vol. 5, No. 4, p. 12; Vol. 5, No. 4, p. 21
Plating; Vol. 4, No. 4, p. 17
Platinum; Vol. 4, No. 3, p. 5
PLTROL Computer Program; Vol. 5, No. 2, p. 18
Powder Metallurgy; Vol. 4, No. 4, p. 37; Vol. 4, No. 4, p. 41; Vol. 5, No. 1, p. 16; Vol. 5, No. 2, p. 24; Vol. 5, No. 13, p. 14
Precious Metals; Vol. 4, No. 3, p. 5
Preforms; Vol. 5, No. 2, p. 24
Printed Circuit Boards; Vol. 4, No. 3, p. 22; Vol. 5, No. 2, p. 11; Vol. 5, No. 2, p. 37; Vol. 5, No. 3, p. 38; Vol. 5, No. 4, p. 36
Production Costs; Vol. 5, No. 3, p. 3; Vol. 5, No. 3, p. 11; Vol. 5, No. 3, p. 14; Vol. 5, No. 3, p. 22; Vol. 5, No. 4, p. 3; Vol. 5, No. 4, p. 21; Vol. 5, No. 4, p. 30
Projectile Manufacture; Vol. 4, No. 4, p. 20; Vol. 5, No. 3, p. 14
Propellant Charges; Vol. 4, No. 4, p. 24; Vol. 5, No. 4, p. 46
Qualification Tests; Vol. 5, No. 1, p. 35; Vol. 5, No. 3, p. 14
Quenching; Vol. 5, No. 4, p. 40
Radar Systems; Vol. 4, No. 3, p. 12
RADFRG Computer Program; Vol. 5, No. 2, p. 18
Radiator Elements; Vol. 4, No. 3, p. 20
RIA (Rock Island Arsenal); Vol. 4, No. 4, p. 15; Vol. 5, No. 1, p. 45
Ricochet Tests; Vol. 5, No. 3, p. 14
Rings; Vol. 5, No. 1, p. 40; Vol. 5, No. 3, p. 11; Vol. 5, No. 3, p. 28
Rocket Motor Cases; Vol. 4, No. 3, p. 29; Vol. 4, No. 4, p. 24
Roll Forming Machine; Vol. 5, No. 3, p. 22
Rolling; Vol. 5, No. 2, p. 18; Vol. 5, No. 3, p. 11
ROLLING Computer Program; Vol. 5, No. 2, p. 18
ROLTEM Computer Program; Vol. 5, No. 2, p. 18
Rotary Forging; Vol. 5, No. 1, p. 45; Vol. 5, No. 2, p. 7
Rotary Swaging; Vol. 5, No. 1, p. 45
Rotating Electrode Process (REP); Vol. 5, No. 1, p. 16
RSI (Rationalization, Standardization, and Interoperability Program); Vol. 4, No. 4, p. 15
Ruthenium; Vol. 4, No. 3, p. 5
Safety; Vol. 5, No. 2, p. 33
Scales; Vol. 5, No. 4, p. 30
Screen Printing; Vol. 4, No. 3, p. 8
Segmented Molding; Vol. 5, No. 3, p. 22
SHAPE Computer Program; Vol. 5, No. 2, p. 18
Shaped Tube Electrolytic Machining (Stem); Vol. 5, No. 1, p. 35
Shell Molds; Vol. 4, No. 4, p. 45
Shells; Vol. 5, No. 2, p. 18
Shrouds; Vol. 5, No. 4, p. 21
Silver; Vol. 4, No. 3, p. 5

Silver; Vol. 4, No. 3, p. 5;
Vol. 5, No. 2, p. 11
SMITHS (Spinning Mass Integrated Terminal Homing Seeker); Vol. 5, No. 4, P. 12
Spinner Tubes; Vol. 4, No. 4, p. 22
Spray Quenching; Vol. 5, No. 4, p. 40
Square Bend Process; Vol. 5, No. 1, p. 40
Stainless Steel; Vol. 5, No. 2, p. 11; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 3
Standardization; Vol. 5, No. 4, p. 30
STP (Standard Temperature Profile); Vol. 4, No. 3, p. 23
Subarray Modules; Vol. 4, No. 3, p. 18
Superalloys; Vol. 4, No. 4, p. 41; Vol. 5, No. 1, p. 35; Vol. 5, No. 1, p. 45; Vol. 5, No. 3, p. 11; Vol. 5, No. 3, p. 28
Super Plastic Forming; Vol. 5, No. 3, p. 42
Swaging; Vol. 5, No. 1, p. 45
T-Shapes; Vol. 5, No. 1, p. 40
TAC (Tactical Air Command); Vol. 5, No. 3, p. 14
Tailcones; Vol. 5, No. 3, p. 26
Temperature Characteristics of Resistance (TCR); Vol. 4, No. 3, p. 9
Thermal Imaging Techniques; Vol. 4, No. 3, p. 22
Thermograms; Vol. 4, No. 3, p. 26
Thickness Measurement; Vol. 5, No. 2, p. 7
Titanium; Vol. 5, No. 1, p. 16; Vol. 5, No. 1 p. 40; Vol. 5, No. 2, p. 3; Vol. 5, No. 2, p. 18; Vol. 5, No. 2, p. 28; Vol. 5, No. 3, p. 33; Vol. 5, No. 3, p. 42
Tooling; Vol. 5, No. 1, p. 20; Vol. 5, No. 2, p. 42; Vol. 5, No. 2, p. 45; Vol. 5, No. 3, p. 3
Track Shoes Manufacturing; Vol. 5, No. 2, p. 18
TRACKS Computer Program; Vol. 5, No. 2, p. 18
Tungsten Contamination; Vol. 5, Nd. 1, p. 16
Turbine Blades; Vol. 4, No. 4, p. 45; Vol. 5, No. 1, p. 35; Vol. 5, No. 2, p. 18
Turbine Engines; Vol. 4, No. 4, p. 41; Vol. 5, No. 3, p. 11
Ultrasonic Bonding
Ultrasonic Bonding;
Vol. 4, No. 3, p. 7
Ultrasonic Testing; Vol. 5, No. 2, p. 7
Ultraviolet Curving; Vol. 5, No. 3, p. 38
UUT (Utility Tactical Transport Aircraft System); Vol. 5, No. 1, p. 20
UUT (Unit Under Test); Vol. 4, No. 3, p. 23
VHSIC (Very High Speed Integrated Circuits); Vol. 4, No. 3, p. 3
Viper Missile Systems; Vol. 4, No. 4, p. 24
Voltage Coefficient of Resistance (VCR); Vol. 4, No. 3, p. 9

NOTE: All the Army ManTech projects listed in this index were conducted under the guidance of the Office of Manufacturing Technology, DARCOM.

US Army ManTech Journal

The Key to Mobilization

Volume 6/Number 2/1981

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Contents

1 **Comments by the Editor**

3 **Guest Editorial: Manufacturing Technology and Industrial Readiness**

5 **Brief Status Reports**

9 **Chem-Braze Abradable Seal Practical**

13 **Responsive Technology In Cannon Making**

18 **Rigid-Flex Saves Cost, Space**

24 **In-Process Microcircuit Evaluation Automated**

28 **Auto Tests for Pneumatics**

32 **Rational Design Increases Output**

38 **Mini Flexible System Versatile**

44 **Large Titanium Compressor Cast**

Inside Back Cover - Upcoming Events

ABOUT THE COVER:

Laser infusion of a previously plasma sprayed test coupon is seen as reflected in the same copper mirror which is delivering the laser energy to the coupon. In this high power carbon dioxide laser surface modification, the intense heat of a rectangularly shaped pattern of laser beam energy is being used to improve the quality of the plasma sprayed surface layer as well as the strength of the bond between the layer and the material substrate. The technique, which has been developed at Battelle's Columbus Laboratories, is being proposed for a wide variety of applications including the hardening of bearing surfaces on Army tank tracks. This application is expected to dramatically extend the practical life of Army tanks in the field. Photo courtesy of Stanley L. Ream, Physical Sciences Section, Battelle.

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Comments by the Editor


RAYMOND L. FARROW

Another milestone has been reached in this issue of the U.S. Army ManTech Journal with the presentation of our first guest editorial on Page 3. Richard Kotler long has been one of our most helpful advisors and has played an active role in the shaping of policy and guidelines for our new format. A member of the Advisory Committee of the magazine and also Technical Advisor representing the U.S. Army Missile Command, Mr. Kotler is known among service mantech people as a dynamic, innovative personality who exercises decisive initiatives in carrying out his active responsibilities. His editorial commentary will elicit much thoughtful response among readers. Industrial readiness truly is a critical capability much affected by our mantech activities.

The cover of this issue shows an exciting new development in surface technology that may dramatically extend the useful lives of moving parts whose wear surfaces are subjected to severe environments — such as tank tracks, which universally are short lived. Initial indications are that this new application of the laser in manufacturing will bring about a whole new level of standards in quality of components used under difficult conditions.

The article by Mike Ross on Pratt and Whitney's titanium castings is based on another outstanding paper presented at the Tri-Service Metals Manufacturing Technology Program Status Review over a year ago. The review series was sponsored by the Metals Subcommittee of the Manufacturing Technology Advisory Group. This MTAG subcommittee is to be commended on its demonstrated ability to pull together an outstanding group of presentations of ManTech projects from all three services. Most of these projects have been reported during the past year in previous issues of the U.S. Army ManTech Journal.

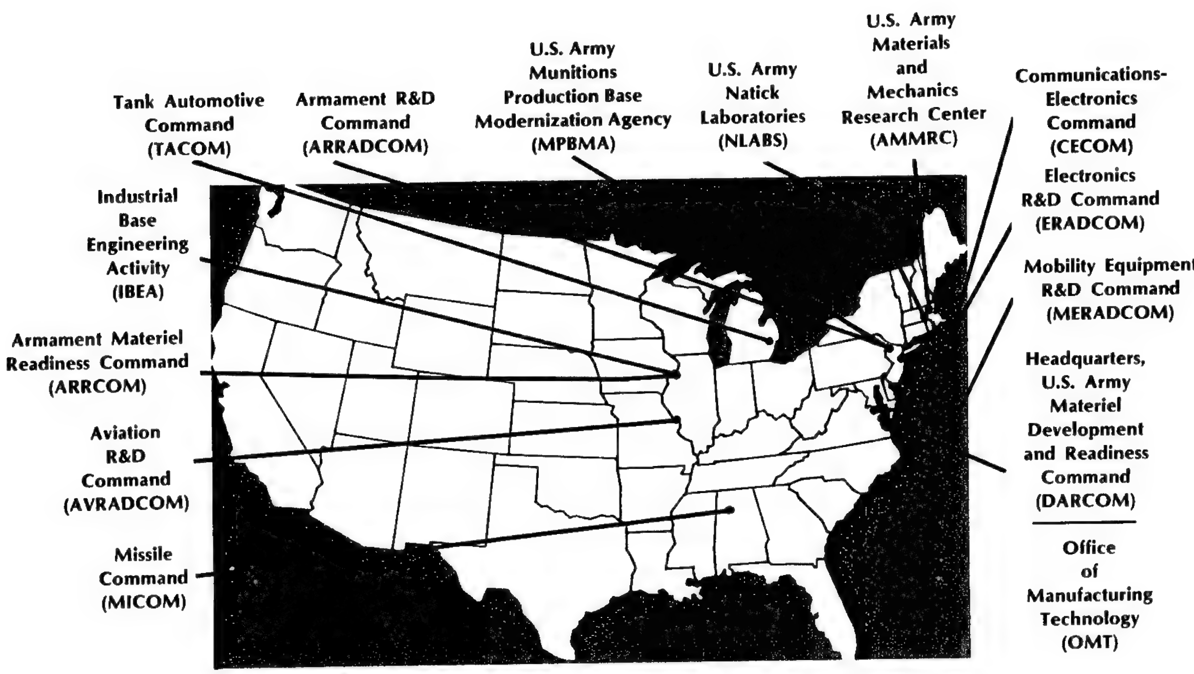
We continue our featuring of advanced academic programs in manufacturing with articles on Purdue University's excellent computerized manufacturing system models and Virginia Polytechnic Institute's miniature flexible manufacturing system. Both schools' manufacturing engineering departments have shown initiative and also concern over our nation's future in establishing these two programs. The methods resulting from this work will enable industrial firms that are implementing new manufacturing systems to save millions by avoiding costly mistakes. Instead, they will be able to design workable, efficient production systems from inception to completion.

An early Army manufacturing technology program that already has paid for itself and will continue to bring benefits for a long time has been that at Watervliet Arsenal, described in the article on 'Responsive Technology in Cannon Making'. Begun in 1965, the program has had spectacular success, reporting a savings-to-investment ratio of 4.7. This arsenal represents one of the nation's primary production base facilities, one which would be highly critical in event of a mobilization requirement. Its current program of re-equipping with new production tools is of great benefit to our nation.

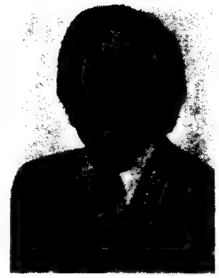
Several other articles in this issue also will draw the attention of our readers. The articles on chem-braze abradable seals, in-process microcircuit evaluation, automatic control actuator testing, and rigid-flex harnesses all describe new ways to produce better hardware more economically and efficiently.

Soon after this issue is in the hands of our readers, it will be time for the annual meeting of the Manufacturing Technology Advisory Group, this time hosted by the U.S. Navy in San Diego. Continuing into the first week of December, this meeting will be an important step toward increased activity in manufacturing technology. Our activities undoubtedly will play a key role in meeting the national goals set by the current administration.

DARCOM Manufacturing Methods and Technology Community



RICHARD A. KOTLER is Manager, Manufacturing Technology, Engineering Directorate of the U. S. Army Missile Command. After joining MICOM following his graduation in 1967 from Tennessee Technological University in Industrial Engineering, he has held continually more responsible positions in numerical control and computer aided manufacturing programs, printed circuits, and hybrid microcircuits; he is a member of the International Society for Hybrid Microcircuits. He received his MBA from Vanderbilt this past year, and serves as Coordinator of Command MICOM Manufacturing Methods and Technology programs.



MM&T: A Major Role

Manufacturing Technology and Industrial Readiness

Recently, considerable attention has been focused on the subject of industrial readiness and the ability of defense suppliers to provide sufficient quantities of essential defense material in times of national emergency. Much of this attention—and concern—results from an increasingly widespread recognition that the readiness of the defense industrial base has deteriorated significantly in the last decade and that this trend is continuing.

The capability and responsiveness of the defense industrial base is of vital importance to our national security. There is little doubt that in the long term, the capability of U.S. industry significantly exceeds that of our adversaries. However, it could take several years to reach full scale mobilization. Further, this leadtime has been increasing to the point where serious doubts arise about the ability of inventories of weapon systems and repair parts to sustain our Armed Forces until mobilization level production can be reached. Similarly, the defense industrial base must maintain an adequate "surge" production capability, short of full scale mobilization, to respond to a variety of limited emergencies that could arise.

Can the defense industrial base respond to these surge and mobilization production requirements in the time frame needed? This is precisely the question addressed by several recent investigations, including a 1980 Defense Science Board study on industrial responsiveness. The Defense Science Board panel found that among other things:

1. Productivity growth in the defense sector has been lagging.
2. Leadtimes and costs have risen dramatically.
3. The supplier base has decreased.
4. There is a growing dependence on foreign sources for critical material and components.
5. Serious shortages exist for engineers, technicians, and skilled blue collar workers.
6. The defense industry has little or no capability for surge production in the short term.

All told, the Defense Science Board's findings were not encouraging. If the defense industrial base is to be capable of increasing production rates, then corrective action is required on many fronts.

One important means for improving industrial readiness is through the use of new manufacturing technology, such as that generated under the Army's Manufacturing Methods and Technology (MM&T) program.

New manufacturing processes and equipment can enhance industrial responsiveness in several ways. First, new manufacturing technology can dramatically increase the productivity of existing facilities and production workers. One of the best examples of this type of productivity improvement is through application of computer aided design, manufacturing, and testing (CAD/CAM/CAT), where tenfold increases in productivity are not uncommon. There are thousands of other examples that could be cited where new manufacturing processes and equipment have allowed manufacturers to significantly increase production output with the same or fewer resources.

Second, new manufacturing technology can help reduce our dependence on foreign nations for critical and scarce materials, either through reducing the amount required or by making material substitutions practical. "Near net shape" manufacturing processes, for example, can reduce material purchases substantially by eliminating much of the scrap generated during traditional manufacturing methods. Similarly, one current Department of Defense manufacturing technology project is establishing production methods for producing high purity silicon crystals for detectors that will reduce our dependence on foreign sources for this material.

Other potential benefits of new manufacturing technology include:

- Reducing the impact of labor shortages through the application of automation and CAD/CAM/CAT techniques
- Shortening production leadtimes by using such methods as computer aided process planning and flexible automation
- Simplifying the production process required for complex defense material.

The Army's MM&T program, in addition to being a major source of new manufacturing technology, also plays another important role in increasing industrial preparedness; namely, it gives defense contractors an incentive for developing and implementing new processes and equipment through cost sharing of high risk developments and by sponsoring Industrial Productivity Improvement Programs and similar efforts aimed at implementing new technology.

Obviously, new manufacturing technology is not a panacea; it will not solve all of the industrial base readiness problems. However, it can play a major role in improving our mobilization and surge production capability if properly focused.

Not surprisingly, the Defense Science Board panel recommended that increased emphasis be given to the Department of Defense's Manufacturing Technology program. I think that most program participants—both in Government and industry—would agree wholeheartedly.

Brief Status Reports

NOTE: The briefs listed in this issue of the U.S. Army ManTech Journal refer to projects added to the Army's MM&T program during the second half of Fiscal 1980. The U.S. Army Industrial Base Engineering Activity prepared the report carrying this listing, operating under the overall supervision of the Directorate for Manufacturing Technology, DARCOM.

Project 3717. High Temperature Turbine Nozzle For 10KW PU. Super alloy metals used in Hot Components of gas turbines are limited in operating temperature and are subject to premature failure in dusty or corrosive atmosphere. Alloy metals are strategic materials and are costly to manufacture. For additional information, contact J. Arnold, (703) 664-5459.

Project 3747. LACV-30, Skirt + Finger Components. Fabrication of skirt, fingers and cones is currently highly labor intensive, leading to high component replacement costs. For additional information, contact J. Manzione, (703) 664-5498.

Project 3759. Kevlar Cable Reinf For Military Bridges. To provide light weight reinforcement tension member having high tensile properties and modulus. For additional information, contact J. Peterson, (703) 664-5176.

Project 3036. CAD/CAM of Special Electronic Circuits (CAM). Semiconductor integrated circuits needed for special communications equip. Must be custom designed for each new application. Each IC requires several mask sets and a number of IC are required for each device. Considerable artwork is required. For additional information, contact J. Kelly (201) 544-3276.

Project 3056. Electroluminescent Numeric Modules. High contrast numeric readouts are required for sunlight legibility and full environmental operation in tactical equip. Electroluminescent modules needed to fulfill this requirement are available only as small qty, high cost, lab built samples. For additional information, contact R. True, (201) 544-5557.

Project 3031. 10.6 UM CO-2 Tea Lasers. Lasers constructed in unit quantities are expensive and vary in specifications. Present range finder lasers have reduced all weather capabilities and are ineffective against countermeasure smokes. For additional information, contact C. Fox, (201) 544-4931.

Project 5110. Common Module Detector Arrays. Mercury-cadmiun telluride detector arrays are now hand lapped and polished. Contact masking is used for photolithography and wet etching for delineation. Also, gold wiring is used for leadouts. These are labor intensive and non-uniform. For additional information, contact E. Lambert, (201) 544-1861 and R. Callender, (201) 544-1263.

Project 8063. Improved Methods of MFG of Butyl Rubber Handwear. The present method of standard butyl rubber glove for OW protection is by a sole source dipping process which requires close quality and environmental supervision increased cost and limited durability and protection. For additional information, contact H. Madnick, (617) 653-2031.

Project 8066. Continuous Filament Helmet Preform. Conventional mode of molding the pasgt helmet i.e. weaving kevlar yarns into fabric cutting preform and laying up, is very wasteful. For additional information, contact R. McManus, (617) 653-2949.

Project 5054. Laser Surface Hardened Combat Vehicle Components. Present methods of surface hardening inputs heat over large surface area. For additional information, contact C. Houston, (313) 574-5814, 1814.

Project 5082. Flexible Machining SYS (FMS) Pilot Line F/TCV Components. Parts for tracked combat vehicles are typically not manufactured in large quantities. Because of this, mass production technologies that result in lower production costs are not used. For additional information, contact S. Goodman, (313) 574-6433.

Project 5097. Integrally Cast Low Cost Compressor (Phase III). Turbine blades and discs must have adequate low and high cycle fatigue properties. Axial compressor stages are designed as separately bladed assemblies. For additional information, contact D. Cargo, (313) 574-5814.

Project 6011. Springs From Fiber/Plastic Composites. Steel springs for tactical vehicles are heavy and subject to failure from fatigue. Carbon fiber composites are lighter and have excellent fatigue resistance. For additional information, contact D. Ostberg, (313) 574-5814.

Project 6053. Welding Systems Integration. Of all metal working processes employed in tracked combat vehicles manufacturing, welding is the most labor intensive and after machining, the most costly. Auto-

mation which could reduce these costs is as yet an unachieved goal. For additional information, contact D. Pyrce, (313) 574-5814.

Project 7183. Semi-Auto Comp Manuf Sys F/Heli Fuselage Secondary Struc. Helicopter fuselage structures have high manufacturing cost due to high part count and high assembly costs. Methods of composite fabrication have been investigated but hand operations result in high labor costs. For additional information, contact E. Dean, (314) 544-1625.

Project 7197. Fabrication of Integral Rotors By Joining. Current gas turbine rotors are either integrally cast or the blades and disks are separate units. The blisk concept does not permit optimum mechanical properties of the unit and the other method requires complex and expensive machining. For additional information, contact J. Lane, (314) 544-1625.

Project 7200. Composite Engine Inlet Particle Separator. Currently, fabrication of the T700 inlet particle separator (IPS) involves machining of castings and forgings and the joining of these parts by welding and brazing. This is costly in terms of both material and labor. For additional information, contact D. Cale, (314) 544-1625.

Project 7319. Prod Meth F/Digital Addressable Multi-Legend Display Switch. Experimental versions are expensive and difficult to manufacture because the mounting of the commercially available electronics display chips and switches must be done by hand to obtain proper ruggedness and operation of the structure. For additional information, contact Brad Gurman, (314) 544-1625.

Project 7322. Low Cost Transpiration-Cooled Combustor Liner. Combustor liners of advanced gas turbine engines are required to survive using less cooling airflow than heretofore available. State of the art transpiration cooled liners can meet the requirements but manufacturing processes are not cost effective. For additional information, contact R. Bolton, (314) 544-1625.

Project 7338. Composite Tail Section. The potential cost and weight advantages of composites for airframe components have not been fully demonstrated due to fabrication limitations related to configuration restraints, for example, in-place winding, complex contours, and co-curing. For additional information, contact J. Tutka, (314) 544-1625.

Project 7339. Filament Wound Composite Flexbeam Tail Rotor. Filament winding from a solid flexbeam to an open spar section, winding to net shape, improved resin control and tolerance control must be obtained to enhance the cost effectiveness of flexbeam tail roters. For additional information, contact Dan Haugan, (314) 544-1625.

Project 7340. Composite Main Rotor Blade. Current production composite blade programs have not been oriented toward optimizing manufacturing techniques/processes related to blade configurations, fabrication methods, and improved structural reliability. For additional information, contact J. Tutka, (314) 544-1625.

Project 7341. Structural Composites Fabrication Guide. The need exists to document industry experience in composites so that cost and manufacturing comparisons can be made. For additional information, contact Dan Haugan, (314) 544-1625.

Project 7342. Pultrusion of Honeycomb Sandwich Structures. Fabrication of honeycomb sandwich panels is labor intensive and face-to-core bonding often takes two cure operations. Pultrusion can be used for continuous production but commercial parameters and tooling are not suitable for military use. For additional information, contact N. Tessier, (314) 544-1625.

Project 7351. Composite Shafting For Turbine Engines. Current material capabilities associated with high speed gas turbine engine shafting require excess bearings and carefull design regarding shaft dynamics. For additional information, contact J. Gomer, (314) 544-1625.

Project 7370. Ring Wrap Composites. Large irregular shaped or long airfoil profiles present special problems when attempts are made to filament wind these configurations. For additional information, contact J. Pratcher, (314) 544-1625.

Project 7371. Integrated Blade Inspection System (IBIS). Inspection of turbine engine blades and vanes

necessitates high accuracy. The effort is time consuming and susceptable to error. For additional information, contact B. Park, (314) 544-1625.

Project 7376. Auto Inspect and Precision Grinding of SB Gears. Current MFG method for spiral beval gears is labor intensive, requiring contact pattern checks with expensive master mating gears. This pattern shifts with a change in torque and temperature. As a result the current tooth form experiences great stress. For additional information, contact D. Pauze, (314) 544-1625.

Project 7412. Infrared Detector for Laser Warning Receiver. Supply of gallium arsenide etalons for use as IR detectors is limited. Methods for diffusing the detector junction, for surface passivation, for bonding the interdigitated etalon to the interdigitated detector are largely hand methods. For additional information, contact Gerald Gorline, (314) 544-1625.

Project 1021. CPPP Machined Cylindrical Parts (CAM). Present manual method for production process planning of machined cylindrical metal components are inadequate due to high process planning costs and a lack of standardization. For additional information, contact R. Kotler, (205) 876-2065.

Project 1026. Production of Low Cost Missile Vanes. Metal control vanes, fins and missile fairings cause high cost, weight penalties and long lead time. For additional information, contact E. Croomes, (205) 876-1740.

Project 3445. Precision Machining of Optical Components. Existing precision machining facilities cannot keep up with the demand, meet optical design requirements, meet production schedules, and stay within reasonable cost boundaries. For additional information, contact W. Friday, (205) 876-8611.

Project 1318. Est Chem Prod + Fill Close + Lap Tech F/XVX2 XM736. The QL process for VX binary MFG results in large quantities of waste, and organic phosphorous compounds. Prior procedures for disposal (deep well) are no longer acceptable. New techniques are required. For additional information, contact C. Heyman, Autovon 584-4286.

Project 4225. Red Water Pollution Abatement System. Red water produced in volume from the purification of TNT is a pollutant for which a satisfactory disposal method does not exist. For additional information, contact W. Buckley, Autovon 880-3572.

Project 4285. TNT Equivalency Testing for Safety Engineering. Present criteria for blast resistant structures is in terms of surface burst of hemispherical TNT. In structural design, to protect from the output of other enegetics, the designers must have data pertinent to the material in question. For additional information, contact J. Marsicovete, Autovon 880-3906.

Project 4341. Improved Nitrocellulose Purification Process. Existing nitrocellulose purification facilities were built in early 1940's and are in deteriorated condition. The used dates base to WW1 and consumes large quantities of energy and water. For additional information, contact G. Buckalew, Autovon 880-4243.

Project 4344. Estab DF Waste Disposal Tech for M687 Binary Project. Large quantities of solid wastes are generated during DF MFG. There is no acceptable disposal method. Drum storage is not feasible and landfill may require special preparation. For additional information, contact C. Heyman, Autovon 584-4286.

Project 4417. Process Technology For Blending RP Smoke Compositions. Smoke produced from HC has led to some injuries and is suspected of being a carcinogen. R+D work is being done to develop a red phosphorus mix to replace HC. However no large scale RP Preparation facilities currently exist. For additional information, contact M. Smith, Autovon 584-3223.

Project 4454. Auto Insp Device Explos Charge Shell (AIDECS). The present method of inspection loaded projectile utilizes a standard radiographic FLM method. Labor and material (Film) are costly. Determination of critical defect is subject to human judgement, fatigue, and error. For additional information, contact G. Drucker, Autovon 880-6264.

Project 6054. Advanced Metrology Systems Integration. The metrology methods used in military vehicle

manufacture, in general, employs contact gauges manually employed. This represents a substantial part of the cost of our military vehicles. For additional information, contact B. Roopchand, (313) 574-5814.

Project 6057. XMI Combat Vehicle. Materials and manufacturing processes employed in the MFG of the XM1 can be improved by incorporating new technologies to the current system. This will enable the XM1 to be manufactured more economically. For additional information, contact G. MacAllister, (313) 574-5814.

Project 7113. Composite Rear Fuselage Manufacturing Technology. Application of composite materials to airframe fuselage components possesses a large potential for cost and weight savings. However, production manufacturing processes have not been established for large, full-scale, compound curvature, components. For additional information, contact D. Orlino, (314) 263-1625.

Project 7143. Ceramic Gas Path Seal-High Pressure Turbine. Metallic systems currently used in high pressure turbine seals degrade due to erosion, corrosion, and adverse rub behavior resulting in increased clearances over the turbine blade tips and loss of engine performance. For additional information, contact R. Bill, (314) 263-1625.

Project 7155. Cost Effective Manuf Meth F/IMPVD High Perf Helicopter Gears. Demand in helicopter operation of greater reliability of high performance gears at lower cost has required that improved processing and evaluation techniques be instituted. For additional information, contact E. Kinas, (314) 263-1625.

Project 7298. High Temperature Vacuum Carburizing. Gear carburizing is presently carried out with a relatively slow endothermic process, typically at 1700 DEG F, which requires surface protection against decarburizing during the cycle or a post heat treat removal of the decarburized layer. For additional information, contact P. Fopiano, (314)544-1625.

Project 7300. Improved Low Cycle Fatigue Cast Rotors. Integrally cast turbine engine rotors have been shown to be cost effective. However, investment casting results in large grain sizes in the disk region and this reduces fatigue life compared to wrought material. For additional information, contact J. Lane, (314) 544-1625.

Project 7302. Production of Boride Coated Long Life Tools. Airframe components and printed circuit boards of fiberglass and other composites are difficult to machine. Tool life is 5-10 PCT compared to use on titanium workpieces. Titanium diboride (TIB2) coated tools are better but not economical. For additional information, contact Dan Haugan, (314) 544-1625.

Project 7202. Application of Thermoplastics to Helicopter Secondary Struc. Forming fiber reinforced thermoplastic components into complex, multi-curved structural configurations, with uniform fiber distribution, minimum warpage, and acceptable dimensional tolerances has not been established for aircraft components. For additional information, contact R. Rodgers, (314) 544-1625.

Project 7285. Cast Titanium Compressor Impellers. Current centriugal compressor impellers are fabricated by machining the flowpath and blade surfaces from a forging. This results in a substantial loss of material and expensive machining operations. For additional information, contact M. Galvas, (314) 544-1625.

Project 7288. MMT Determination of Optimal Curing Conditions. Current methods of curing composites are based on empirical determination of required processing conditions. A trial and error procedure is followed until the manufacturer is reasonably satisfied with mechanical properties. For additional information, contact D. Granville, (314) 544-1625.

Project 7291. Titanium Powder Metal Compressor Impeller. When complex configurations, such as centrifugal impellers and compressor rotors are utilized in gas turbine engines, typically high manufacturing cost are encountered. For additional information, contact J. Lane, (314) 544-1625.

No Photo Available

MILTON LEVY is Corrosion Research Group Leader, Metals Research Division, U. S. Army Materials and Mechanics Research Center. He has been the recipient of the Army Research and Development Achievement Award and the AMMRC Director's Award in Science. He has authored more than thirty papers covering the areas of aqueous corrosion, stress corrosion, corrosion fatigue, high temperature oxidation and sulfidation, and protective coatings. He received a B.S. in Chemistry from Boston University and did graduate work at Boston University and the University of Maryland. Mr. Levy presented a paper on surfact treatments at an MTAG Metals Subcommittee meeting in Hyannis, Massachusetts last summer. He is a member of the American Chemical Society and the Electrochemical Society and has served on the Metals Properties Council.

Breakthrough Achieved by AVRADCOM

Chem-Braze Abradable Seal Practical

Cost savings of 74% due to less expensive materials and faster, easier fabrication are in store for the U.S. Army Aviation Research and Development Command with its new chemical brazing technique for attaching abradable seals to compressor blades.

An improved Chem-Braze bonding system for attaching sintered abradable seals, such as FELTMETAL, to titanium, steel, and nickel base compressor blade tip shrouds has been developed. The improved Inhibited Chem-Braze (ICB) system incorporates glycerin as an inhibitor to prevent premature evaporation which prolongs working life and allows adequate time to attach abradable seals to engine hardware. This project was accomplished by the Pratt & Whitney Aircraft Group for the U.S. Army Aviation Research and Development Command.

Various types of seal attachment methods have been used in the manufacture of gas turbine engine compressors. FELTMETAL, a sintered fiber abradable material, has shown advantages of abradability, erosion

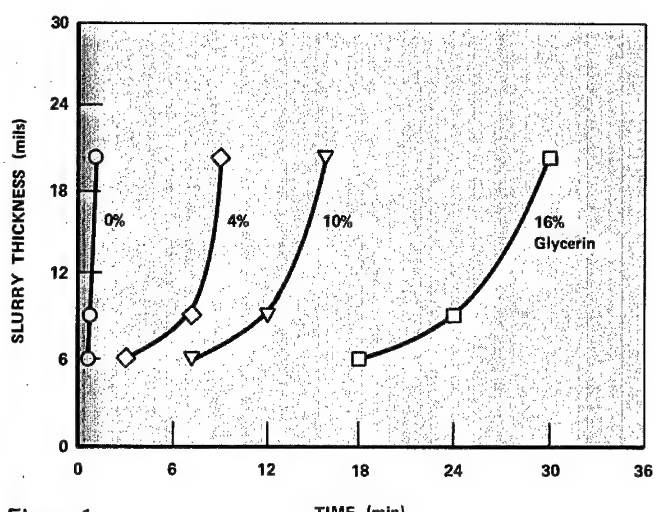


Figure 1

NOTE: This manufacturing technology project that was conducted by Pratt & Whitney Aircraft Group was funded by the U. S. Army Aviation Research & Development Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The Project Engineer is Mr. Milt Levy, U. S. Army Materials & Mechanics Research Center, (617) 923-3331.

resistance, and reliability for blade tip shroud sealing. Sintered abradables would be desirable throughout the compressor for shroud base alloys of titanium, steel, and nickel, but this system incorporated a gold-nickel braze.

Although effective, the attachment of sintered abradables with metallurgical brazes is relatively expensive and not particularly suited for refurbishment. Removal of the abradable is accomplished by grinding and/or machining, which occasionally causes distortion of lightweight compressor case hardware.

Because of these disadvantages, P&WA/Florida developed the Chem-Braze bonding system for attaching abradable sheet materials like FELTMETAL to compressor case assemblies for blade tip-shroud sealing. The system has demonstrated its viability, with attachment involving simple mechanical fixturing and curing and removal facilitated by chemical stripping. All operations are relatively fast and inexpensive.

However, experience with the Chem-Braze (Sermabond 481) bond system had shown the need for an improved composition. The prior system did not provide adequate working time to permit easy attachment of abradable seals to full scale hardware. Premature evaporation of Chem-Braze before abradable seals could be mated to metallic substrates occasionally produced substandard bonding. the requirement for a chemical addition to the existing composition to inhibit evaporation and prolong its useful working life was apparent.

Manufacturing Parameters Established

Selection of an inhibitor was based on its miscibility with Chem-Braze and its ability to inhibit evaporation of the existing composition. Alcohols, glycols, ketones, hydrocarbons, arenes and other chemicals were investigated, but only glycerin met both criteria. Figure 1 shows that, as glycerin concentration increases, ICB working life increases.

Initial tensile strength testing of abradable seals attached with ICB revealed the need for an undercoat. The tests showed adhesive failures—that is, failures which occurred at the ICB-substrate interface. Application of 0.001 to 0.003 in. thick undercoat of Metco 405 nickel-aluminide eliminated these adhesive failures. Tensile strength tests determined that a working environment of 60 to 65 F and 60 % relative humidity is preferable.

Having selected an effective inhibitor, undercoat, and preferred working environment, the optimum inhibitor concentration remained to be defined. Chem-Braze containing up to 4 volume percent glycerin does not provide adequate working time. That containing 13 or more percent glycerin is too fluid to attach abradables to engine-size hardware. Compositions of 7 and 10% ICB demonstrated acceptable working lives and viscosities. Vibration and tensile strength tests showed the 10% ICB bonds to be superior. Also, the 10 % glycerin concentration allows a 10 minute dwell time (the time between applying bonding cement to components and the actual mating and application of pressure to the assembly). This is a reasonable dwell time for attaching seals to engine hardware using the ICB bonding system.

Attaching porous, abradable seals to compressor case blade tip shrouds with ICB slurry requires optimizing slurry thickness and bonding pressure. The quality of ICB bonds was determined by visually inspecting bond joints formed after attaching intentionally deflected FM515B abradable seals to glass slides. CB slurry thickness of 0.010 in. and 200 psi bonding pressure were established as preferred manufacturing guidelines.

After mating abradable seals to metal alloys with ICB and applying pressure, it is necessary to dry and cure the ICB to complete the bonding process. Metallography was employed to determine that drying for a minimum of 12 hours at ambient temperature followed by 1 hour at 175 F minimizes porosity in ICB bonds. A cure cycle similar to that established for the prior Chem-Braze composition was established. Figure 2 lists all of the

1. Apply Metco 405 undercoat to metal substrate
2. Add 10 volume percent glycerin to SermaBond 481
3. Apply 0.010 in. thick ICB slurry
4. Mate seal to substrate and apply 100 to 200 psi load
5. Dry at 60 to 65 F for minimum of 12 hours
6. Dry at 175 F for 1 hour
7. Increase temperature at 1 F/min to 200 F and hold 1 hour
8. Release load
9. Increase temperature from 200 to 450 F at 5 F/min and hold 1 hour
10. Increase temperature to 700 F at 10 F/min and hold 1 hour
11. Increase temperature to 1000 F at 10 F/minute and hold 1 hour

Figure 2

selected manufacturing parameters to summarize the entire process.

The above procedure was used to prepare tensile test samples. Test results for these seal attachments demonstrated that the procedures produce high quality ICB bonds.

Chemical Stripping Helps

Prior experience demonstrated the suitability of a chemical stripping technique for removing abradable seals which are attached using the original Chem-Braze bonding system. It was shown that the same stripping technique can be used to easily remove seals which are attached with the improved ICB bond and prepare the substrate for refurbishment. Immersion in aqueous sodium hydroxide at 180 F for up to 1 hour followed by water rinsing and light grit blasting completely prepares hardware for refurbishment.

As a test, the entire process of rebonding virgin abradable seals was repeated using the selected ICB manufacturing process except for the application of a Metco 405 undercoat. It was judged that the original undercoat remained intact and did not need to be replaced. This fact demonstrated just how light the grit blasting operation is and its suitability for use with lightweight compressor hardware. Tensile strength test results for original and refurbished seal attachments showed tensile strengths of 535 and 620 psi. respectively. An increase in strength for the refurbished seal attachment demonstrates that the chemical stripping technique is suited for ICB bonds.

Tooling Techniques Inexpensive

Tooling requirements include the means to dispense ICB slurry onto mating components and to apply bonding pressure. Initial trials involved painting ICB slurry onto metal substrates, but it quickly became apparent that this method was incapable of controlling slurry thickness. Therefore, a doctor blade was selected to dispense controlled slurry thicknesses onto substrates, as shown in Figure 3. Doctor blade tools are inexpensive and eliminate operator technique as a variable. It was also found that painting the surface of the abradable seal with just enough ICB slurry to wet it completely prior to mating components produced higher quality bonds.

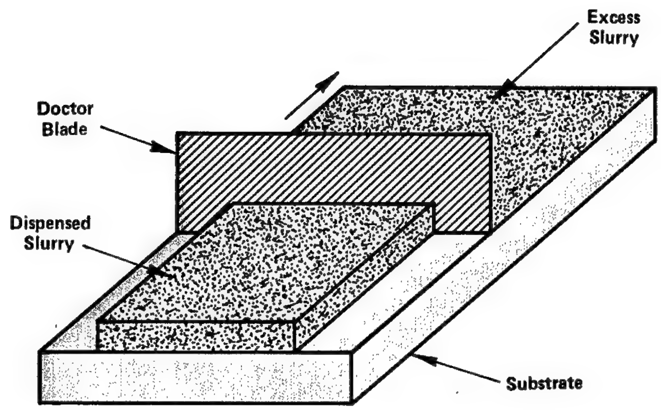


Figure 3

To uniformly apply fixturing and bonding pressure to the seal and substrate, three tooling schemes were investigated. The use of expandable ring segments was selected over the more complex liquid nitrogen shrink fit tooling and air bag tooling.

Since ICB seal attachment only involves application of pressure up to 200 F, inexpensive tooling could be constructed. Wooden expandable ring segments with neoprene rubber inserts were fabricated, as shown in Figure 4. The segments were used to apply fixturing and bonding pressure while attaching FM515B abradable seals to simulated engin hardware. An assembled view of the expandable ring segments, abradable seals, and simulated engine hardware is shown in Figure 5. Use of the rubber inserts permitted application of a uniform load and compensated for dimensional variations in tooling, seals and hardware. This fact was substantiated by strain gage measurements, which demonstrated that the selected bonding pressure range was maintained throughout the drying cycle.

The feasibility of the selected tooling method was demonstrated by attaching abradable seals to simulated engine hardware. High quality bonds were produced in the demonstrations. Voids which were attributable to inexperience in handling engine-size seals were present in a few localized areas. The voids were not related to the use of the selected composition, manufacturing guidelines, or tooling techniques. Titanium, steel, and

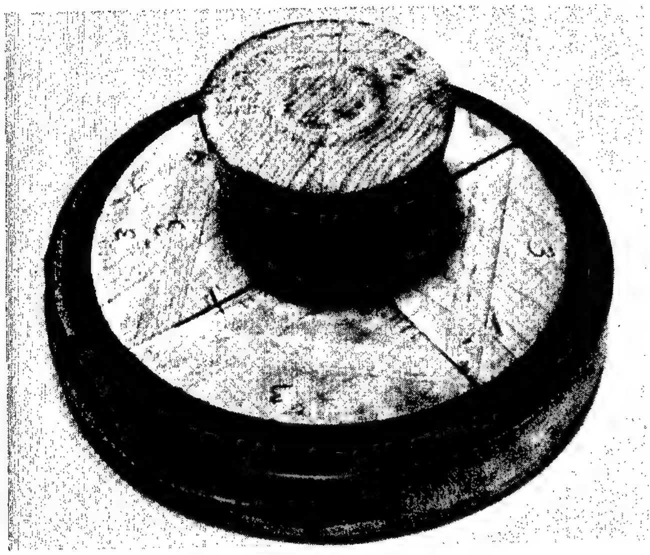


Figure 4

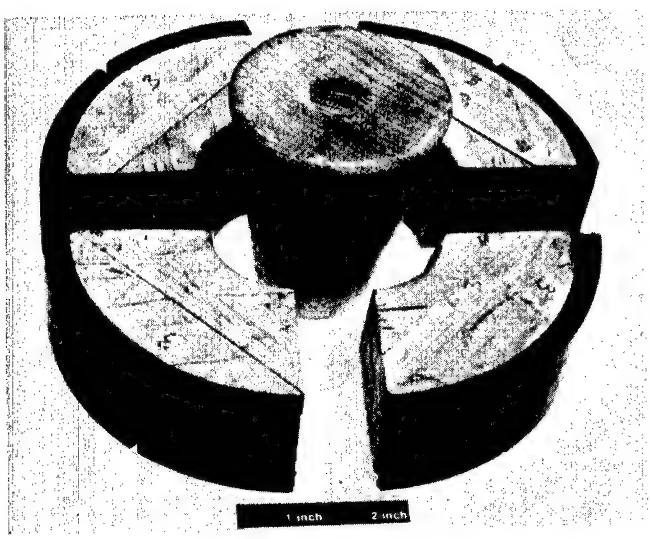


Figure 5

nickel base alloys formed identical bonds with the abradable seals in this demonstration.

Significant Cost Savings

Both labor and materials savings contribute to the economic attractiveness of the ICB system. A preliminary economic analysis shows a 74 % cost savings for attaching abradable seals with the ICB bonding technique compared to attachment with gold-nickel braze. The comparison was based on the attachment of FM515B abradable seals to a common compressor stage which contains three separate seals.

The relative costs for the two procedures expressed as a percentage of the total cost for gold-nickel braze attachment are shown in Figure 6.

	MATERIALS		
• Chem-Braze	0.1	• Gold	25.9
• Glycerin	0.2	• Nickel	0.1
• Nickel Aluminide	1.0		
	1.3		16.0
	LABOR		
• Undercoat	16.8	• Plating and Flashing	63.0
• Dispense Slurry and Fixture	3.9	• Heat Treatments	21.0
• Dry and Cure	4.0		
	24.7		84.0
Total	26.0%		100.00%

Figure 6

Relative Costs for Seal Attachment to A Common Compressor Stage

The comparison includes materials and labor costs for the two braze techniques only. It does not include the cost of abradable seals, tooling, and processing equipment. Since seal costs are identical in both cases and the ICB technique involves relatively low temperature processing, it is reasonable to assume that inclusion of these items in a thorough comparison will result in the ICB technique being even more economically attractive.

MM&T at Watervliet Arsenal

Responsive Technology in Cannon Making

GERALD L. SPENCER is the project leader for the Production Base Support Program, Industrial Readiness Division, and coordinates the ManTech program at Watervliet Arsenal. He holds Bachelor Degrees in Chemistry and Mechanical Engineering. He received his Master's Degree in Management from Rensselaer Polytechnic Institute and is a registered professional engineer in New York State. For the past four years he has served as Chairman of the Technical Working Group on Manufacturing Methods & Technology. Previously, he worked as a mechanical engineer in Benet Weapons Laboratory on the development of the 8 inch M201 cannon.

Savings totaling 74.3 million have been attained by Watervliet Arsenal as a result of an ongoing MM&T program. From 1965 to the present, $15.7 million in new manufacturing methods and technology has been put to work at the famous New York State arsenal.

Approximately half of these funds have been used to buy prototype equipment, most of which is currently being used in cannon production. Based on savings generated, the savings-to-investment ratio amounts to an impressive 4.7, which over the past 15 years has yielded a return on investment of 129 percent.

Man-Hours Saved

In terms of productivity, MM&T projects alone have generated considerable labor savings in the period 1965-80. A good example of such savings is the reduction in the hours needed to manufacture a 105mm M68 cannon tube (shown in Figure 1). Labor time has been reduced by 35 hours—a 36 percent reduction, with MM&T accounting for 11 of the hours saved.

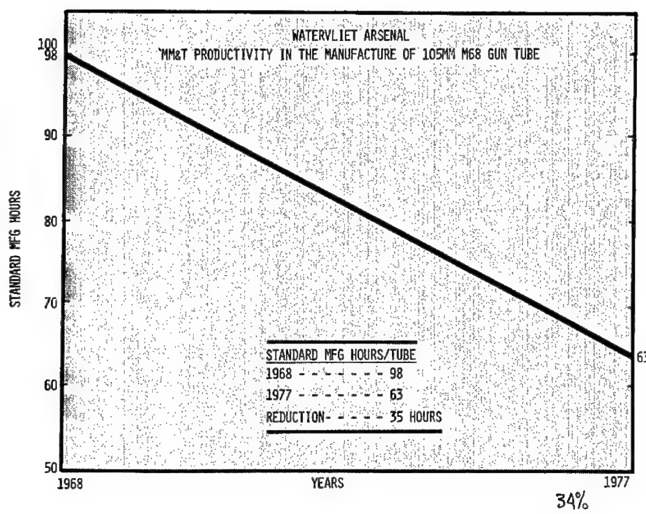


Figure 1

Hydraulic Autofrettaging and Swaging

Figure 2 shows an 8" M201 Howitzer being swage autofrettaged. Swaging is a simple process in which a hydraulic ram forces an oversize mandrel down the bore of the tube, causing permanent bore enlargement which

NOTE: These manufacturing technology projects that have been conducted at Watervliet Arsenal were funded by the U. S. Army Armament Materiel Readiness Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The Project Engineer is Mr. Gerald L. Spencer, (518) 266-5535.

Figure 2

creates favorable residual stresses. These techniques have strengthened cannon tubes, increased their fatigue life, and reduced cannon weight, thereby saving material costs and increasing the mobility of weapons. If it were not for this process, cannon tubes would require thicker and heavier walls or multipiece jacketed construction to obtain the same fatigue life as autofrettaged tubes. In addition to the improvement in these important performance characteristics, the total savings are impressive, as shown in Table 1.

Savings	Cannon	Weapon	Time Period
$41,279,733	175mm M113	M107 Self-Prop. Field Artillery Gun	FY '65 to '77
$$6,548,000	8 inch M201	M110A1 Self-Prop. Heavy Howitzer	FY '78 to FY '82

*Estimated cost avoidance based on first year of production.

Table 1

Bore guidance was an MM&T development that was implemented in the early '70s. This project revolutionized the manufacture of gun tubes, reducing boring time for large caliber gun tubes from 92 to 16 hours. A guided boring system was developed to detect and automatically correct off course or eccentric boring on long cannon tubes. In the guided boring head illustrated in Figure 3, an accelerometer senses eccentric motion and signals a servovalve that produces hydraulic corrective forces to restore the alignment of the boring head with the centerline of rotation. This produces a straighter bore and significantly reduces rework and total machining time. In the prior process of wood pack reaming, straightness deviations of 0.100 inch were considered good, and occasionally this process produced a scrap tube. Guided boring guarantees a straightness deviation of less than 0.005 inch, the thickness of a razor blade, and **has never produced a scrap tube**, which would cost $5,000 to $20,000 per tube. One guided boring machine has replaced three wood pack boring lathes, a significant reduction in floor space. Because of the increased accuracy of this

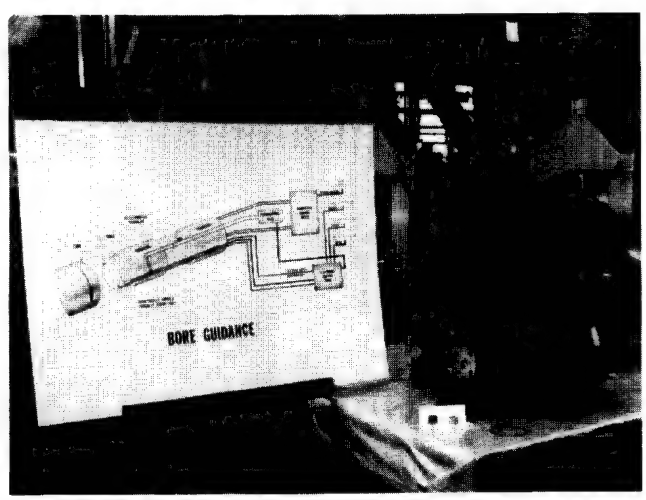


Figure 3

process, problems in attaining proper stock distribution after boring have been reduced and smaller diameter forgings can be purchased, saving material costs.

Special equipment (illustrated in Figure 4) was designed to machine the step threads on large caliber breech rings and breech blocks. The "step" or interrupted thread design maximizes the breech block engagement area while minimizing the rotary movement to open and close the breech. The machine oscillates the breech block back and forth—similar to a washing machine agitator—simultaneously machining two sectors to size. The threading tools, which are mounted 180 degrees apart, are full form tools that contain the necessary teeth to machine all threads of each sector. This new step threader has reduced machining time on the 8 inch M201 breech block by 3.5 hours. Similarly, a step threader has been developed that machines the internal step threads of the breech ring, resulting in an 8 hour savings per breech ring.

Figure 4

A dual rifling process that increases 105mm M68 gun tube rifling production has recently been implemented. Because gun tube specifications require close dimensional control and surface finishing, rifling grooves have always been costly and time consuming to produce. Other attempts to reduce rifling costs were unsuccessful until the dual rifler was developed. This machine simultaneously broaches the rifling on two tubes without undue strain on the equipment. Besides the benefit of a 40 percent reduction in rifling costs, additional advantages include

- Reduction of needed floor space
- Reduction in setup time
- Reduction in manpower.

An abrasive grinding machine (shown in Figure 5) was developed to machine cylindrical components of breech mechanisms. This machine uses a carbide roll

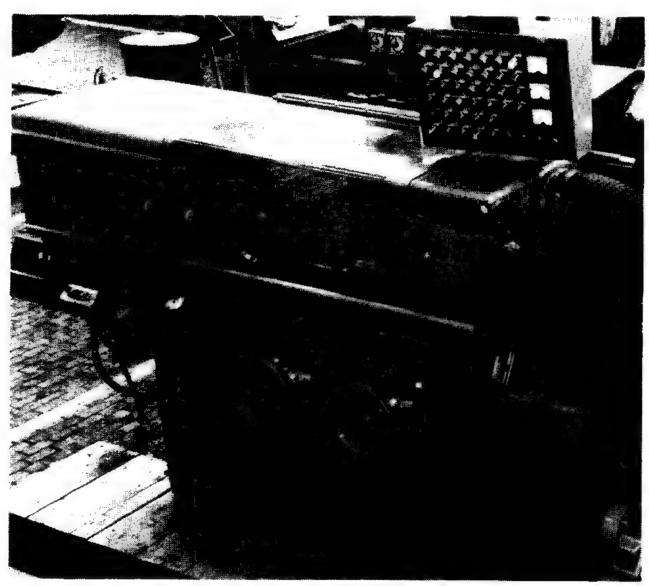
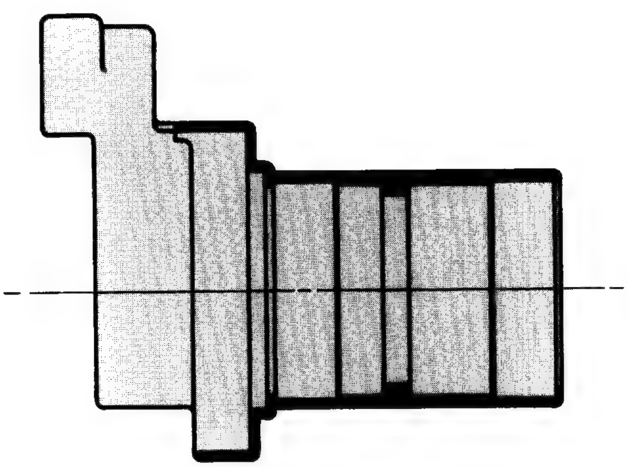


Figure 5

that is contoured the same as the component. The carbide roll crush dresses the form onto the grinding wheel, which in turn removes stock at a rapid rate and produces the desired contour on the component. As demonstrated by Figure 6, the use of this technique has reduced the machining time of a 105mm M68 breech component from 1.25 hours to just thirteen minutes, an impressive 83 percent reduction in time. Much of the high metal removal rate is credited to the 11,000 feet per minute surface speed, the jet wheel cleaner, and the coolant nozzling that flushed the swarf away from the wheel face.

This highly productive technique was further implemented with an additional machine to produce tensile specimens. The machine was acquired under the QRIP, Quick Return on Investment Program, and it will be amortized in less than two years.

CRANK D8765800 – 105 MM M68 GUN



Stock removed by abrasive machining – 7.3 cu. in. = 2 lb

Current machining method:
Average time, floor to floor – 75 minutes

Abrasive machining method:
Average time, floor to floor – 13 minutes

Figure 6

Rotary Forge

Rotary forge technology was developed by MM&T projects in the late '60s and early '70s. The rotary forge and associated heat treat facility were designed, acquired, and installed in the 1973-1976 time frame.

Presently, this is the largest rotary forge machine with hollow capability in the Free World, and it has added tremendously to Watervliet Arsenal's capabilities and readiness. One 105mm gun tube forging can be produced on this rotary forge in about 7 minutes.

Diversity in Manufacturing Pays Off

Other projects showing the range and diversity of manufacturing technology efforts include the following:

- Simulation devices for Quality Assurance acceptance testing such as the gymnasticator for the 105mm M68 breech mechanism.
- Projects which measure fatigue life of cannon tubes by laboratory cycling, thereby reducing fatigue testing costs and extending the safe service of cannon tubes.
- Metallurgical projects such as rapid heat treating, horizontal spray quenching, and improved castings for muzzle brakes.
- Inspection and testing processes, such as the automatic gun tube inspection station which effects more efficient and accurate final inspection of gun bores (see Figure 7).

Production Methods Implemented

Watervliet is constantly striving for increased productivity and recognizes the value of a strongly innovative

MM&T program. Equally important is the transition of completed MM&T projects into production. Several years ago, a Technical Working Group (TWG) was established with members from the Arsenal Operations/Manufacturing area and project development scientists and engineers of Benet Weapons Laboratory/ARRADCOM. The TWG is chaired by an industrial engineer from the Industrial Readiness Division. The TWG provides a forum to identify manufacturing problems and to solve those problems with new technology and methods. Projects are proposed, discussed, screened, and time phased into the MMT five year plan at weekly meetings over a four month period. During this planning phase, agreement reached among members that specific projects are needed for the Watervliet Arsenal production base assures acceptance when the project is successfully completed.

Work To Continue

Continued and accelerated ManTech efforts are ongoing to support Project REARM (REnovation of ARmament Manufacturing), a six year effort to replace deteriorated equipment at Watervliet and Rock Island Arsenals. Watervliet staff is confident that future ManTech efforts will further enhance the production base for cannon and enable the Army readiness command to meet its mission both with quicker response and greater productivity.

Figure 7

Uniting Two Technologies

Rigid-Flex Saves Cost, Space

Plasma etching to remove drill smears and use of acrylic adhesives on rigid-flexible laminates proved the most effective method of fabrication of rigid-flex harnesses in an MM&T program for the U.S. Missile Command carried out by McDonnel Douglas Electronics. The technology was documented by a videotape of the process. The optimized process was developed for the routine, cost effective fabrication of rigid-flex multilayer boards. This process can be implemented by industry with minimal conversion cost.

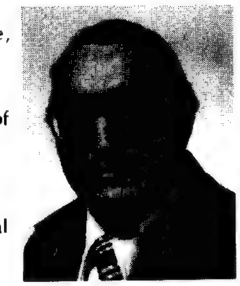
Material savings of $43 per board and yield improvement of 25% are estimated. Martin Aircraft is now producing rigid-flex harnesses, using this same process for the Copperhead system.

Rigid-Flex Benefits

Rigid-flex multilayers are the result of uniting two technologies: rigid multilayer and flexible printed wiring. The product is a multiple layer with integral flexible layers interconnected in the rigid area by plated-through-holes. This rigid-flex approach has some very significant advantages which include:

- Reduced Hardware Costs
- Lower Weight and Space
- Simplified Designs
- Prompt Electrical Check and Error Correction
- Lower Assembly Costs
- Reproducible Circuit Runs
- Reduced Probability for Wiring Errors.

Major problems combining rigid and flexible materials are misregistration, delamination, smear, process incompatibility, and plating anomalies.



ROBERT L. BROWN is a General Engineer at the U. S. Army Missile Command in Huntsville, Alabama. His current projects involve creative direction of contractor engineers on projects such as the fully additive manufacture of printed wiring boards (Hughes), ultraviolet curing of conformal coatings for PC boards (Hughes), product cleanliness techniques for PC boards (Martin-Marietta), laser scan testing of PC boards (Chrysler), rigidflex assemblies (McDonnell-Douglas), and insertion of nonaxial lead devices in locaserts (Martin-Marietta), a recent approved success. A Registered Professional Engineer in Alabama and holder of a B.S. in Metallurgy (1958) from Alabama University, Mr. Brown holds six patents and is author of fifteen technical briefs which NASA rates as equivalencies to patents. He was the first recipient of the NASA "Noteworthy Contribution" award in 1970 for his many contributions to their technical utilization program, and patented several inventions that were used in production. While employed by Chicago Bridge and Iron in 1948 he invented an early television X-ray imaging system, which was the first such system to reach broadcast resolution and was the basis of an X-ray television system built by Zenith Corp. and delivered to Marshall Space Flight Center in 1972. This system was used at Vanderbilt University as the best available nuclear medical imaging system and is still in use there as a television X-ray system. His most recent development of an X-ray imaging system is characterized by revolutionary increases in resolution and performance through use of fiber optic technology, in which 80-100% of the radiation is captured in the image and resolution is more than 20 lines per inch, with increases easily possible through use of finer fibers. Also while at Chicago Bridge and Iron he patented a method for brazing claddings on dissimilar metals which was widely used commercially for many years. A member of the International Society of Microelectronics, Mr. Brown worked as an aeronautical engineer during World War II at Birmingham and also worked as an engineer with the Birmingham Fabrication Company.

Industry Polled

A literature search and industry survey were conducted to assess industry approaches for rigid multilayer, flexible, and rigid-flex printed wiring. As a result of the survey, it was determined that a wide variety of materials were available from suppliers, but users and fabricators of various printed wiring products were selective in their material choices. The predominant material used for rigid multilayer boards was epoxy-glass. The preferred flexible printed wiring materials were polyimide laminates and coverlays with either acrylic or modified epoxy adhesives. A variety of rigid-flex combinations were reported and five of the most frequently listed combinations were selected for fabrication and evaluation according to the characteristics shown in Table 1.

NOTE: This manufacturing technology project that was conducted by McDonnel-Douglas Electronics was funded by the U. S. Army Missile Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. R. L. Brown, (205) 876-1085.

Material Considerations
• Availability • Cost
Process Considerations
• Compatibility with Existing Processes • Laminating Pressure • Absence of Air Entrapment • Minimum Innerlayer Distortion/Registration Problems • Ease of Smear Removal • Good Delamination Resistance in Thermal Shock • Potential for High Yields/Low Cost

Table 1

Tests indicated that the most promising material combination is the following:

Rigid material:	Copper clad epoxy-glass laminate
Flexible material:	Copper clad polyimide, polyimide coverlay, acrylic adhesive
B-Stage:	Limited flow epoxy-glass.

This system exhibited ease of processing, registration integrity, plated-through-hole quality, and resistance to thermal shock. Boards could be routinely fused in hot oil and test tabs subjected to immersion in 500 F molten solder without delamination. An analysis of material cost and availability revealed the system was an attractive alternative to others evaluated.

Process Improves Performance

Critical processing parameters were identified and techniques were implemented to improve the process performance. Improvements were incorporated for coverlay treatments, tooling and layup methods, lamination, drilling, plasma etching, and cleaning/plating methods.

Coverlays Treated

Rigid-flexible board (RFB) incorporates flexible printed wiring as an integral inner layer. In the process of fabricating the flexible printed wiring, a polyimide coverlay is laminated to the bare copper circuitry providing insulation and environmental protection. The slick, shiny surface of the coverlay presents a delamination potential during final RFB processing. The problem is aggravated by the surface variability. It was apparent that untreated coverlays resulted in unacceptably high yield losses from delamination.

Mechanical roughening reduces the sheen of the coverlay surface and promotes improved adhesion (B-stage to coverlay). Because of its simplicity, pumice scrubbing is recommended for coverlay treatment.

Unique Layup

Various tooling and layup techniques were investigated. Figure 1 is an example of one such method. Access windows are provided in the B-stage and thin laminate materials. Subsequent routing frees the flexible areas by removing the surrounding rigid material. Laminating plastic can be placed in the window as filler material for uniform pressure distribution and for control of the B-stage flow; however, it does cause processing problems. Since the plastic material can flow or shift during lamination, it may creep under rigid sections preventing B-stage bonding. Because of the extremely low flow nature of the B-stage, it has been found that good lamination characteristics are achieved with little or no "squeeze out" of the B-stage when no filler material is used. This latter approach reduces the material requirements, eliminates the selective placement of material in window areas and is therefore recommended.

Figure 1 illustrates the use of lagging material (paper), laminating plastic, and release sheet placed inside the laminating plates. The quantities used are dependent on heat input to the stack. Typical times/temperatures are described in the section dealing with lamination. It is advantageous to have the materials inside the plates for good pressure uniformity—which minimizes air entrapment.

Lamination Expels Trapped Air

The initial lamination cycle used was a hot press dual cycle which had performed successfully for rigid multilayer boards. The sequence involved a hot press (340 F), a low pressure kiss cycle (10 PSI) applied until the stack

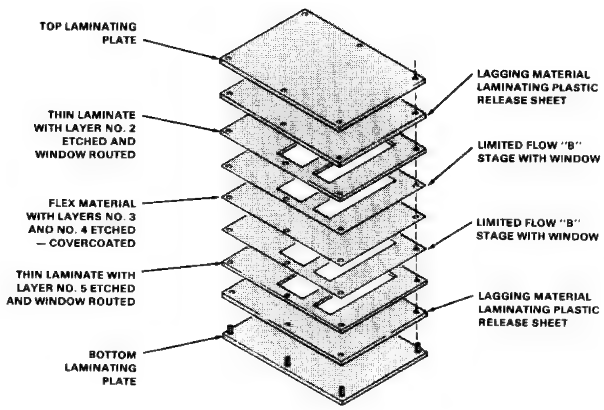


Figure 1

temperature reached 270 F, a high pressure (200 PSI) for one hour, and a cool down cycle under pressure until the stack temperature reached 100 F or less. The application of this cycle to RFB's gave marginal results with respect to air entrapment.

A new approach was selected which yielded excellent results. The lamination cycle incorporates a cold press (100 F or lower) and a single pressure (250 PSI) applied for a total time of 75 minutes followed by cool down under 250 PSI. The temperature is raised to 340 F during the cycle. Figure 2 illustrates a typical sequence.

The time to reach 270 F is important and should be controlled within the 12-20 minute interval. An advantage of the suggested cycle is that air and other volatiles are expelled prior to curing of the B-stage material. With the hot press the combination of edge sealing and premature curing of the B-stage traps air and other volatiles within the composite. The use of the suggested cycle greatly reduces the incidence of air entrapment.

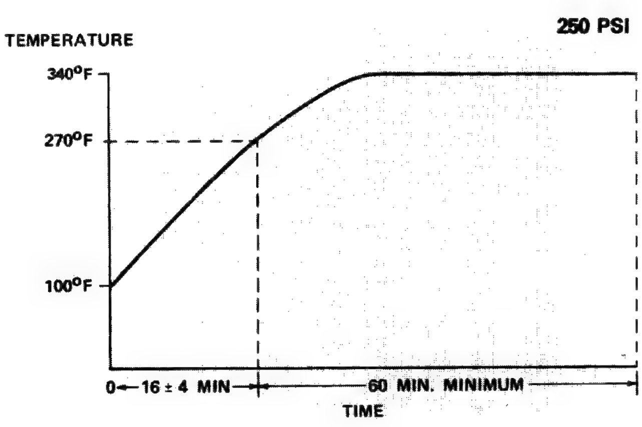


Figure 2

Drilling Simple, Effective

RFB's were drilled with NC drilling machines under conditions quite similar to those used for rigid multilayer boards. Although no conditions could be found which prevented drill smears, quite acceptable drilled holes were obtained with respect to nail heading, gouging, and hole roughness. The use of aluminum foil entry materials and aluminum clad backer material was beneficial for retardation of burr formation and extension of drill bit life. Drill loading is more of a problem with RFB's, and for that reason a maximum drill bit life of 500 hits is recommended. This compares to 1000 hits suggested for rigid multilayer boards.

Plasma Etching of Smears

Since no drilling conditions prevented smears and such smears resist removal by chemical methods, plasma etching is the only smear removal process recommended.

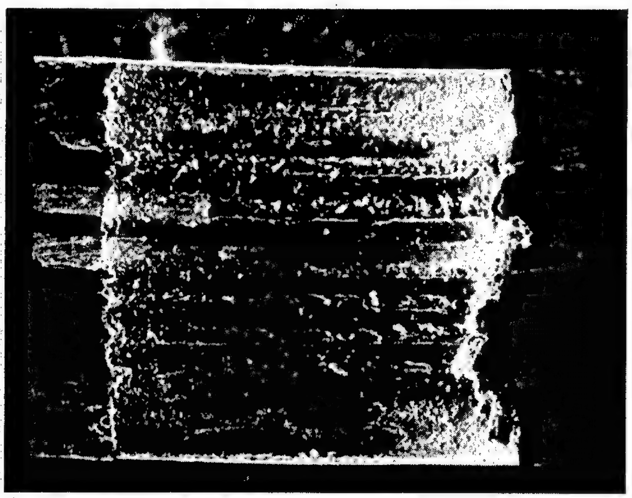
The problem of smear is much more severe with rigid-flex combinations than with rigid multilayers, with the flex adhesives contributing the bulk of the problem (see Figure 3). Chemical smear removal with liquid honing is a possible solution for systems utilizing modified epoxy adhesives and/or no-flow epoxy/glass B stage. Systems using acrylic flex adhesives encounter acrylic drill smears which resist removal by chemical means.

Figure 4 graphically outlines a process cycle for routine plasma etching. Using this cycle and the conditions described in Table 2 yield optimum results. Optimum etching is that which ensures smear removal without excessive attack of the hole wall.

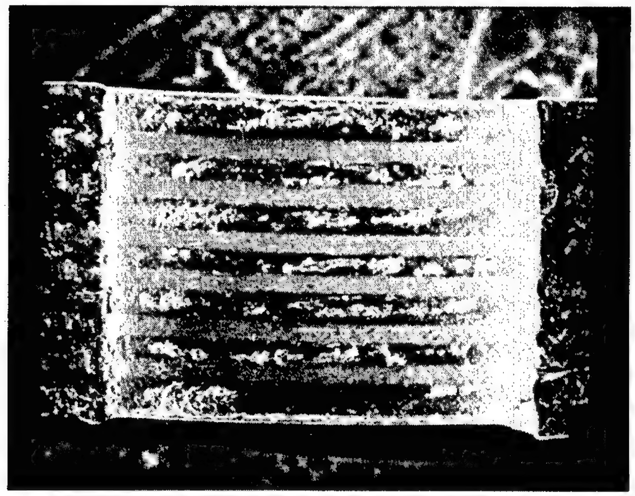
Plasma units of two electrode designs were used. Both units removed drill smears, but it was noted that the plasma unit with parallel plate electrode construction required less etching time than did the unit with the annular electrode design. This is an important factor because long etching times can result in significant heat rise in the board causing delamination. For this reason the parallel plate electrode design is preferred.

Modified Cleaning/Plating

Erratic plating results were obtained when boards were processed through the electroless plating sequence directly after plasma etching without an intermediate



Rigid-Flex Multilayer (As Drilled)
Before Plasma Etch



Rigid Multilayer (As Drilled)
Before Plasma Etch

Figure 3

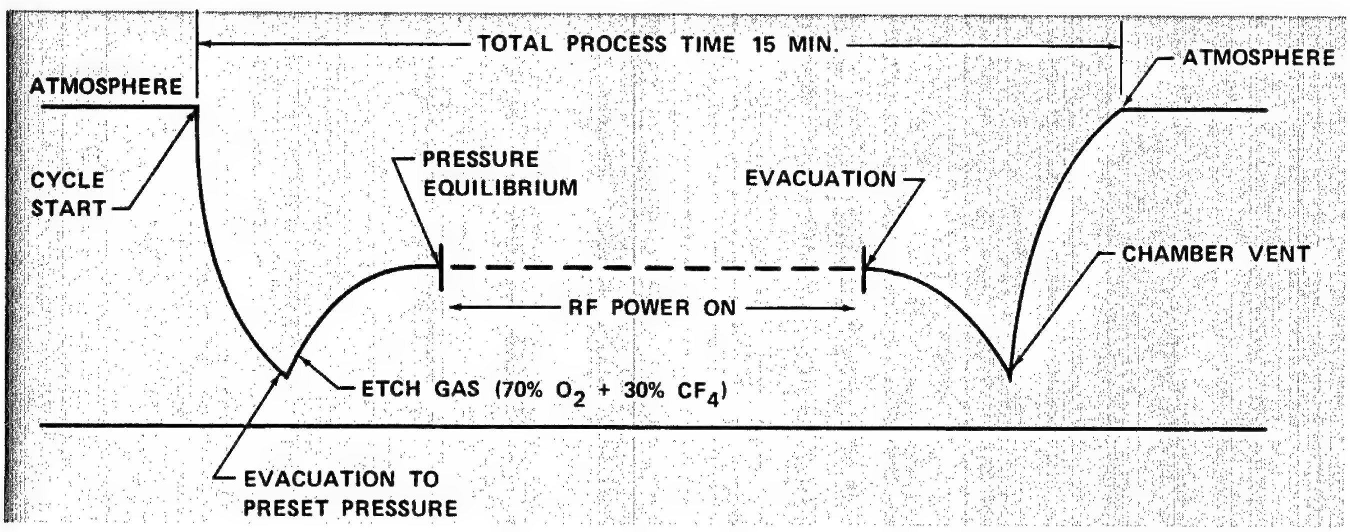


Figure 4

RF Power	1000 – 1300
Chamber Pressure	0.5 Torr
Gas Mixture	70% O_2 + 30% CF_4
Total Cycle Time	15 Min

Table 2

cleaning step. A hot (155 F) alkaline cleaner has been used successfully for rigid multilayer boards for many years. However, it was known that the ten minute immersion time normally used would result in attack of the acrylic adhesive. Efforts were concentrated on modifying this alkaline solution for RFB's. After evaluating several conditions, excellent results were obtained using the conventional alkaline cleaner at a lower temperature (125 F) for a shorter time (two minutes). Excellent hole wall adhesion was consistently obtained using this modified alkaline treatment which is considered necessary for

optimum in-hole plating. Standard plated-through-hole methods were evaluated and proved generally satisfactory.

Prototypes Fabricated

The fabrication sequence generally utilizes conventional equipment and processes used for rigid multilayer and flexible printed wiring manufacturing. The basic process is outlined in Figure 5. Flexible innerlayers were processed with full coverlay lamination. Rigid external layers were processed in a conventional manner.

A representative production line was established using existing facilities. All processes, solutions and equipment were typical of what would be specified for a large scale production line. This line was used to fabricate RFB's of a design selected by the U. S. Army. The particular board selected is shown in Figure 6. It is a six layer RFB with eleven individual rigid areas mechanically and electrically interconnected by flexible wiring. This board is used as a mother board on the Copperhead program.

In addition, a number of RFB's were processed and then subjected to a variety of in-process and final board tests to verify that the selected process was capable of routinely producing RFB's which met applicable standards.

Tests Verify Design

In the absence of industry/government specifications, test specimens were tested to the combined requirements of MIL-P-50884, "PRINTED WIRING, FLEXIBLE" and the Institute for Interconnecting and Packaging Electronic Circuits' IPC-ML-950, "PERFORMANCE SPECIFICATIONS FOR MULTILAYER PRINTED WIRING BOARDS". In addition to the end product tests, numerous in process tests were performed over months of operation. Such tests included cross sectioning samples at critical points in the process to verify the integrity of the drilling, plating, and lamination. Also, boards were subjected to hot oil fusing, and representative test tabs were tested by immersion in molten solder (500 F) for twenty seconds. Excellent results were obtained, verifying both the processing ease and the ruggedness of the RFB's made with the selected process.

Finally, one hundred RFB's of the design shown in Figure 6 have been fabricated and delivered to the U. S. Army. In addition to the above boards, eight boards of a new but similar design were fabricated and delivered at the Army's request to Martin-Marietta. These boards have successfully passed a vigorous acceptance and performance test regimen established for the Copperhead Program.

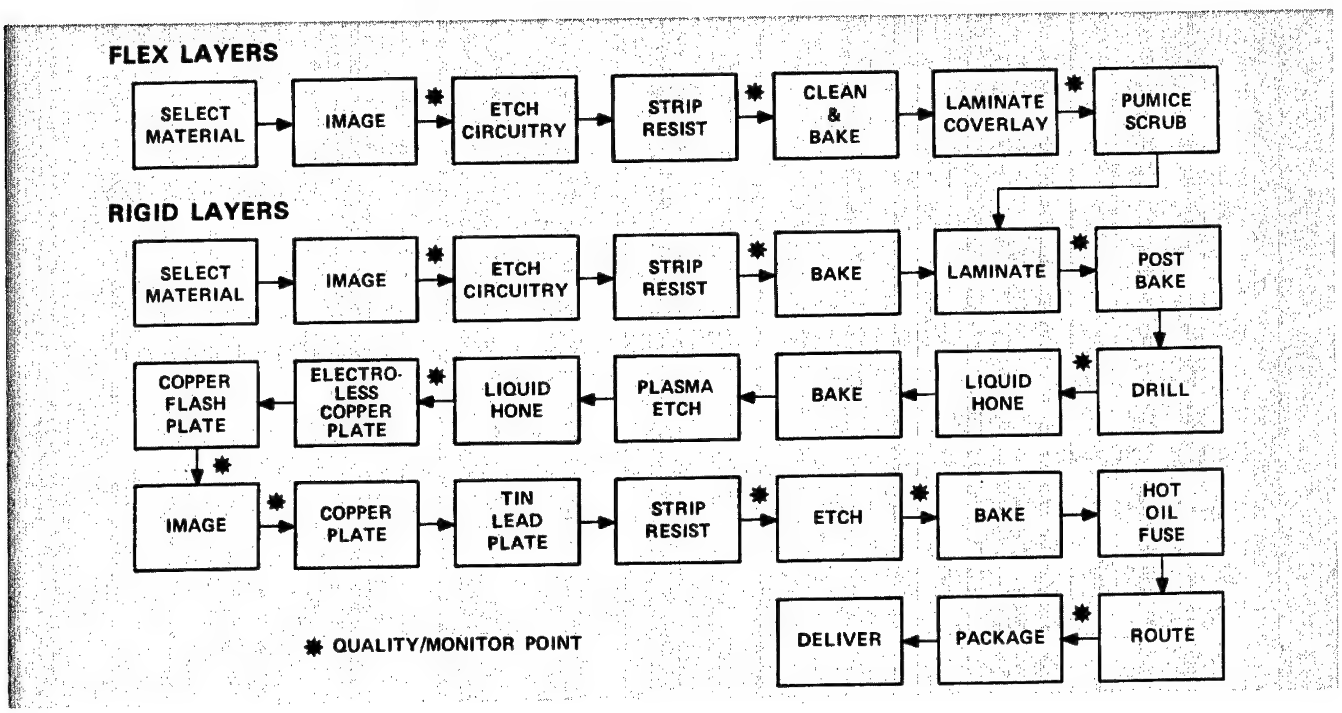


Figure 5

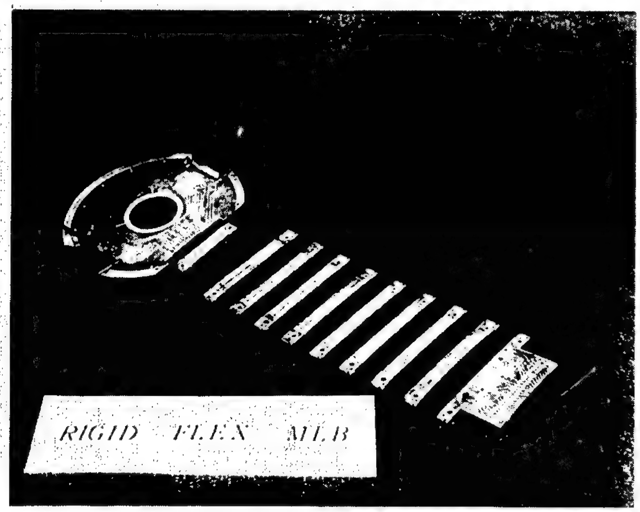


Figure 6

Savings and Yields Substantial

A cost/value analysis was prepared of the developed process, comparing the costs of the end product before and after the MM&T study. This was accomplished by evaluating material savings and by estimating dollar savings from improvements in yields using the optimized process.

In the absence of a common "before" material system, a typical one has been selected for comparative purposes. Representing the original approach, polyimide-glass laminates and acrylic adhesive are used. In the optimized system, epoxy-glass laminates and limited flow epoxy glass B-stage are utilized. Table 3 shows the material cost breakdown for each system and indicates a per board savings of $43 using the optimized approach.

Based on pilot line fabrication results and an evaluation of the ease of processing of material systems, it is conservatively estimated that a 25% improvement in board yields will be obtained using the selected process. The enhanced yields result from a series of improvements which include better chemical compatibility, reduced misregistration, absence of air entrapment, ease of smear removal, and, finally, excellent delamination resistance in thermal shock.

The labor content of a typical production unit was assessed by a standard time analysis of the process sequence. From this analysis the projected recurring labor cost of production units was estimated to be $250. The cost/value analysis of the optimized process was estimated and is summarized in Table 4.

Original Material System	
Polyimide-Glass Thin Laminate	$20.00
Acrylic Adhesive B-Stage	$50.00
Polyimide Coverlay/Acrylic Adhesive	$14.00
Polyimide Flex Laminate	$21.00
Original Material Cost Per Board	$105.00
Optimized Material System	
Epoxy-Glass Thin Laminate	$7.00
Limited Flow Epoxy-Glass B-Stage	$20.00
Polyimide Coverlay/Acrylic Adhesive	$14.00
Polyimide Flex Laminate	$21.00
Optimized Material Cost Per Board	$62.00
Material Savings Per Board $43.00	

Table 3

Benefits for Industry

The materials and processes described herein permit the routine fabrication of lower cost RFB's. The documented process can be implemented with minimal conversion costs.

At an industry/government debriefing session, over one hundred individuals representing all of the services and every major aerospace firm were in attendance, indicating the widespread interest in this technology.

Production Level	Original Approach*	Optimized Approach**	Cost Δ
1,000 units	$ 710,000	$ 416,000	$ 294,000
3,000 units	$2,130,000	$1,248,000	$ 882,000
5,000 units	$3,550,000	$2,080,000	$1,470,000
10,000 units	$7,100,000	$4,160,000	$2,940,000

*50% Yield
**75% Yield

Table 4

3-Mil Faults Detectable

In-Process Microcircuit Evaluation Automated

ISAAC H. PRATT is Research Project Leader, Electronics Technology & Devices Laboratory, at the U. S. Army Electronics Research and Development Command. He has been active for over twenty-five years in electronics research and development in the Army, specializing in microelectronics, particularly hybrid microcircuits. He also has been heavily engaged in associated microcircuit technologies for assembly, interconnection, and packaging. His area of greatest expertise is in relation to film processing techniques. He is a U. S. Army representative on the MTAG Electronics Subcommittee and is Chairman of the Panel for Hybrid Microcircuits Working Group. He is a member of the Institute of Electrical and Electronics Engineers, the International Society of Hybrid Microelectronics, the American Physical Society, American Vacuum Society, and the International Electronics Packaging Society. He received his B.A. in Chemistry from Queens College of the City College of New York, his B.S. in Electronics Engineering from Monmouth College, and his B.S. and M.S. in Physics from Monmouth College.

Acknowledgement—James F. Kelly, USACECOM, who participated in the project initiation, and John M. Laskey, RCA, for project management.

A new level in efficiency appears feasible in the inspection of microcircuits during manufacture. In a program sponsored by the Electronics Technology and Devices Laboratory of the U.S. Army Electronics Research and Development Command, the Government Systems Division of RCA successfully demonstrated an in-process evaluation system that could inspect up to 750 substrates per hour reliably, detecting faults in excess of 3 mils.

The purpose of this program was to establish a manufacturing and technology program for Automatic In-Process Microcircuit Evaluation (AIME) to develop automatic inspection of thick film conductor lines on substrates and to eliminate microscopes used for visual pre-cap inspection of hybrid assemblies in Army electronic equipment. This MM&T program was the result of work done during the Automated Image Device Evaluator (AIDE) Program. The purpose of the AIDE program was to provide the basis for automated inspection of second generation image intensifier tubes. The current program utilized AIDE hardware components in the design and fabrication of the AIME demonstration model. The data gathering and evaluation task was performed on twelve substrates containing faults typical of those found in the manufacturing process; these faults were tested against a "master" substrate. Faults emplaced in the defective test substrates included breaks in the printed path, excessive ink along a printed path, necking down or narrowing of the printed path, and shorts between two printed paths.

AIME System Simplifies Complex Procedure

Figure 1 shows the physical layout of the AIME system. There are basically two major units of the AIME system: the control/display station and the inspection station. Figures 2 and 3 show the actual units. Figure 4 is a simplified block diagram of the AIME demonstration model; the basic components of the system include the following:

(1) **Control/Display Station**—computer and peripherals, video processor and input/output control, return beam vidicon (RBV) electronics, power supply, sync generator, time base corrector, video disc recorder/reproducer, video monitor, illumination power supplies.

(2) **Inspection Station**—RBV camera head with lens, illuminators (lamps), unit under test (UUT) holding fixture, optical table with the structure/shroud assembly, air conditioner unit.

The legend in Figure 4 identifies those items which are under computer and/or manual control. The legend also shows which of the components were designed and built (new designs), purchased (modifications as necessary), and government furnished equipment — GFE (modified as necessary). All GFE items evolved from the AIDE system.

NOTE: This manufacturing technology project that was conducted by RCA's Government Systems Division was funded by the U. S. Army Electronics R & D Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The ERADCOM Project Engineer is Mr. I. H. Pratt, A/V 995-4258.

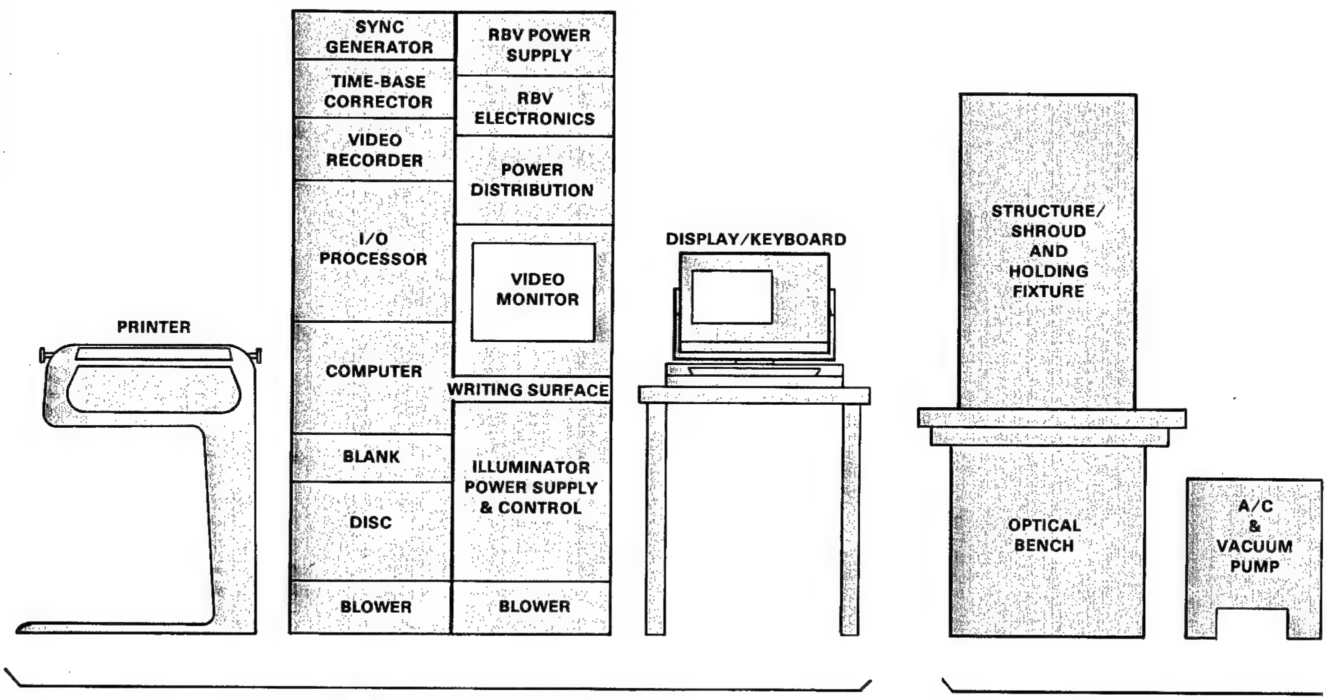


Figure 1

Two Major Inspections Made

There are many points, during the manufacture of hybrid microcircuits at which there is some degree of visual inspection. However, there are specific major points at which 100 percent visual inspection is made. These inspection points occur after thick film processing of the substrate is complete (before the start of assembly) and immediately before sealing of the assembled hybrid package (pre-cap visual). The following is a general description of a typical substrate inspection process performed by the AIME system.

The UUT is placed in the holding fixture and subsequently illuminated, projecting the UUT image on the RBV face. The AIME control selects and positions the RBV scan (via the RBV electronics) to the desired UUT image area to be viewed. The RBV output is a video signal which is directed to the RBV electronics and then to the video processor. A prerecorded image of the same UUT area is obtained from the video disc recorder and directed to the video processor.

Black and White Image Synthesized

The video processor performs two functions.

- First, the difference between the RBV video signal and the video disc recorder signal output is taken, digitized, and fed into the core memory of the AIME system computer.
- Second, the processor takes the same difference in video signal and combines it with the RBV signal, which then is displayed on the color video monitor.

The combination of the difference and RBV video signals is such that the RBV output appears as a black and white image on the monitor. The difference video signal is directed to the red and green gun driver circuits. Thus, if the RBV image is wider than the recorded image the green color gun output will be increased, resulting in a highlighting of the greater than normal UUT area. A similar result is obtained if the UUT image is narrower than the recorded image, except that the red color gun output then is increased.

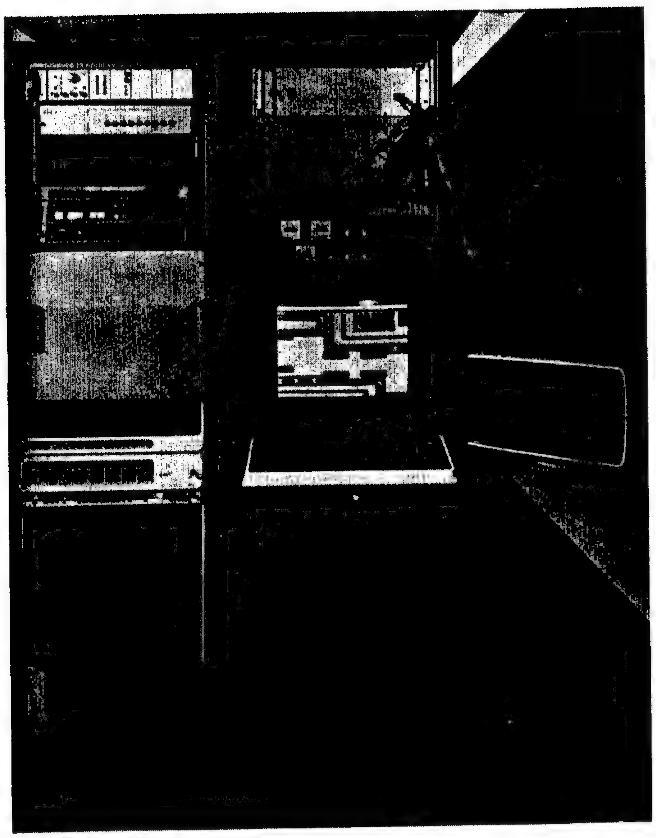


Figure 2

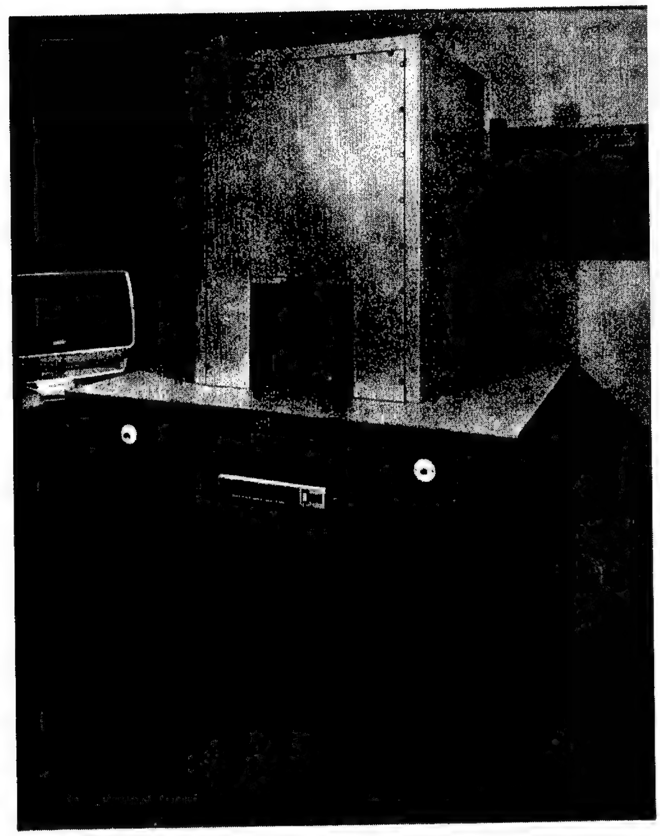


Figure 3

Hybrid Assembly Inspected Similarly

When inspection is complete, the AIME control repositions the RBV beam scan to the next UUT area to be inspected and repeats the above process until the UUT inspection is completed. The hybrid assembly inspection is similar to that described above for the substrate inspection, except that the video disc recorder is not used and the color highlighting of an out of tolerance area is not generated. Finally, three basic operating modes are possible under central processing unit control: manual inspection, semiautomatic inspection, and automatic inspection (demonstration system).

Up to 100% Effective at 750/Hour

The results of data gathering and evaluation indicate that the AIME demonstration system can successfully detect substrate defects of varying sizes. Overall, AIME detected 96.4 percent of all substrate defects. When the defects were classified by size, AIME detected 100 percent of defects three mils or larger and 81 percent of defects of less than three mil size.

Analysis of the high speed capability of the AIME demonstration system indicates that up to 750 substrates per hour may be inspected reliably.

ADDITIONAL DEVELOPMENT REQUIREMENTS

Different Camera Required

The RBV camera presently used on the AIME demonstration system is over twelve years old and no longer is produced. Future development of the technique requires the selection of a suitable replacement for the

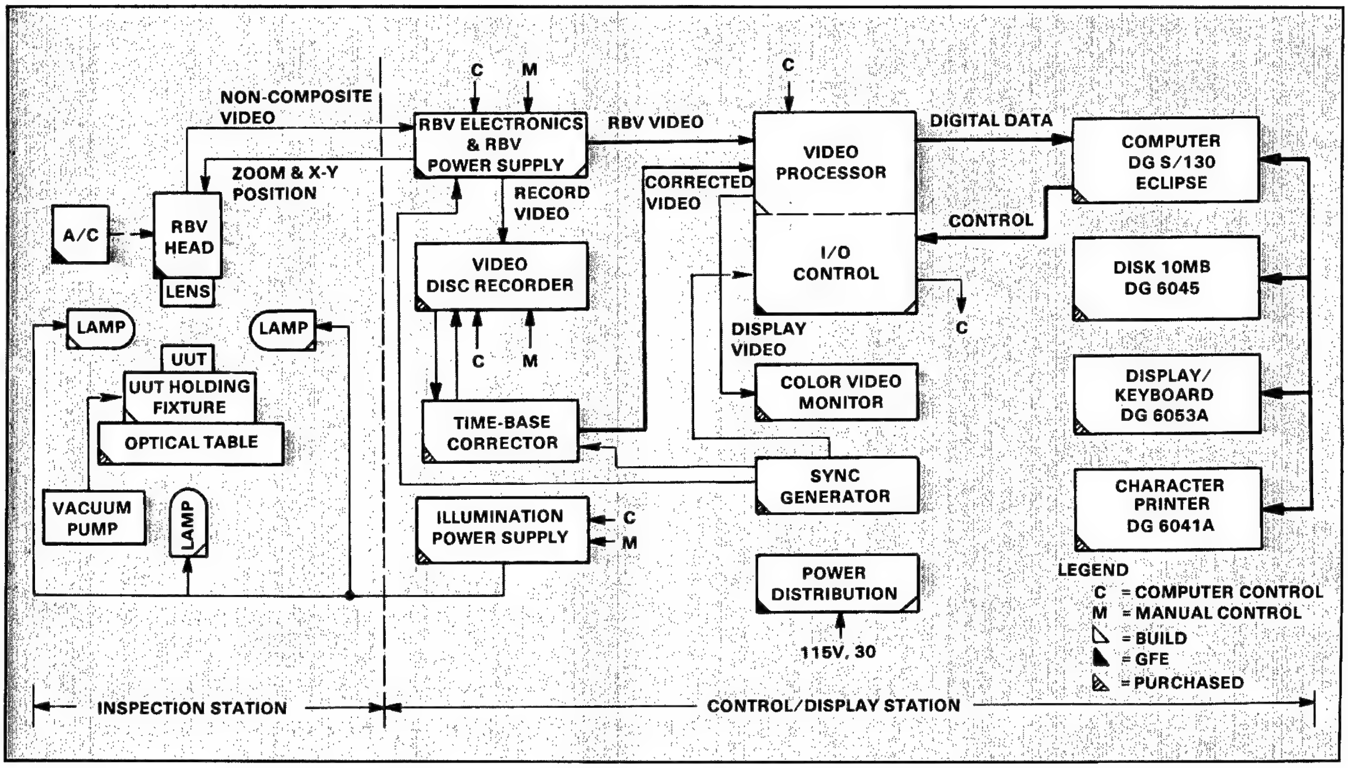


Figure 4

RBV camera. The camera to be chosen for AIME must be capable of high resolution over the entire substrate image area and of providing a readout at a continuous rate with a steady state optical exposure; or — in near-real time storage and readout — with a discrete input consisting of a shuttered exposure. Electronic zoom also would be required without raster burn to preserve high resolution while retaining compatability with standard rate devices and displays.

In conjunction with alternate tube investigation, it is recommended that attention be given to the pre-cap inspection requirement. Alternate methods of zoom ratios, faster scan rates, and special high resolution displays should be considered to provide a high resolution and more practical pre-cap inspection capability, including a stereoscopic view capability for adequate depth perception. In addition, further development may warrant separation of the system into two independent units — one with automatic line inspection capability and one for pre-cap inspection. This will simplify the design of each unit and make each one more economically attractive.

TBC Unit Shows Deficiencies

The time base corrector (TBC) unit in the AIME demonstration system aligns the playback video from the video recorder with the camera video to within 10 nanoseconds. However, the TBC unit currently in use exhibits an inherent instability in the clock signal that provides horizontal lockup on each frame of the video signal. This instability causes the identification of false defects during substrate testing. Correction of this problem requires either partial redesign of the TBC currently in use or the selection of a new unit.

An investigation also is recommended to determine the feasibility and cost effectiveness of replacing the video recorder and TBC with alternate solid state storage devices.

Multilayer Structures Not Studied

The evaluation of substrate defects was confined to single layer films. Multilayer structures required further investigation to determine the effects of layer interferences.

Over 90% Time Savings

Auto Tests for Pneumatics

By
Robert J. Wolowicz
Control Systems Div.
Chandler Evans, Inc.

An automated production test system is now functional for testing gas operated control actuators on Copperhead and U.S. Navy 5 inch missiles that meets Army and Navy specifications. The 10 minute per system test time is now in keeping with required production rates. Obvious labor lost savings will result, both from the need for fewer skilled technicians and from the fewer test hours required (10 as opposed to 250 minutes per unit). The technology developed will prove applicable to systems of similar design.

This test system currently is being calibrated for Copperhead implementation, with an estimated cost savings of $4.4 million. The Navy 5 inch system will incorporate a similar automated test stand.

Chandler Evans Controls System Division of Colt Industries was contracted by the U.S. Army Missile Command to design, fabricate, and demonstrate automated test equipment for testing the pneumatic control actuation systems.

The total test time to perform a complete verification test on a control actuation system which includes load and unload times was reduced from one and one half hours on the Copperhead system and three hours on the Navy system to ten minutes per system. The need for skilled technicians to run the verification test and to perform data analysis was eliminated, and the test equipment can be modified easily to test other control actuation systems.

Previous Operations Costly

Testing of pneumatically operated control fin actuators on small missiles was an exceptionally tedious and time consuming activity. Setup times and documentation procedures were excessive. Signals had to be routed to various instruments, read, and recorded manually. For the COPPERHEAD system, twelve separate tests required eighty minutes. The Navy Guided Projectile required one hundred seventy minutes to functionally test. This manual test procedure was too slow for the projected high production rates.

High Production Rates Necessary

The principle objective of the work was to design and fabricate automated test equipment suitable for use in a high volume production environment for verification

NOTE: This manufacturing technology project that was conducted by Chandler Evans Controls System Division was funded by the U. S. Army Missile Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Joe Byrd, (205) 876-8445.

testing of gas operated control actuation systems. Specifically, the test equipment had to be capable of performing a complete performance verification test on both the Copperhead and Navy 5 inch control actuation systems, yet incorporate those features which would minimize test equipment modification and, as a consequence, minimize system 'change over' costs when adapting the test equipment for use on other programs.

Computer Controls Flexible

A modular test stand design consisting of a main console and two dedicated test beds was the outcome. One test bed is dedicated to the Navy 5 inch system, the other to the Copperhead system. A digital computer with its ancillary equipment resides in the main console. The digital computer controls either test bed and can easily control other test beds as required with software changes. In effect, the test beds simply provide the means for interfacing a particular control actuation system to monitoring and loading devices and to the computer.

Load and unload cycle time was kept to a minimum by designing the mounting fixture so a unit could be secured to it with a minimum of operator motion and without the use of tools. Quick disconnect fittings and lock nuts were used to secure high pressure lines and the unit to the mounting fixture, respectively. As a result, a system load time of two and one half minutes and an unload time of one and one half minutes (for a total of four minutes) was achieved.

Test Time Reduced Sharply

Verification test time was substantially reduced from the present per system test time of one and one half hours on the Copperhead and three hours on the Navy 5 inch to six minutes per system. This result was obtained by changing test procedures and methods in areas that contribute significantly to total test time and by the elimination of the operator in data collection and analysis. Data collection and analysis was set up to be solely controlled and carried out by the computer.

Once the verification test started, the operator could not influence the sequence of events to test completion unless a failed test situation occurred or the self checking feature of the system determined a test parameter unacceptable. In either case, the operator would be notified via the keyboard of the cause of test termination and then would be prompted to either continue or discontinue testing.

Improvement on Many Fronts

The act of removing the operator from the process of data collection and analysis reduced verification test time to about fifteen minutes. The remaining excess test time was eliminated by procedural and method changes in the system duration test, frequency response test, and closed loop position gain test. It should be noted that these changes do not sacrifice information pertinent to determination of the acceptability of a unit that otherwise would be obtained by existing test methods.

Simulated duration was set up to be performed in an abreviated form: a thirty second run for a reduction of fifty seconds in test time. Closed loop position gain and frequency response were set up so each shaft was tested concurrently. This philosophy was used throughout the test program. However, the major reduction in test time was obtained for these two tests. Concurrent testing was economically possible because of the speed and versatility of the digital computer. A saving of two hundred seconds was obtained in the closed loop position gain test. Frequency response test time was reduced about five minutes thru a combination of running the test on each shaft concurrently and also test method modifications. The combination of all the changes mentioned above reduced the total test time to perform a verification test on a Copperhead or a Navy 5 inch to minutes.

Equipment Modular

Figure 1 is a system block diagram which shows the major subcomponents of the three modules a main console, and two test beds. Figure 2 is a photograph of the complete system.

The main console contains all the electronic, pneumatic, and mechanical equipment common to most any control actuation system test stand. It is divided into two mechanically distinct sections, electronic (upper half) and pheumatic (lower half).

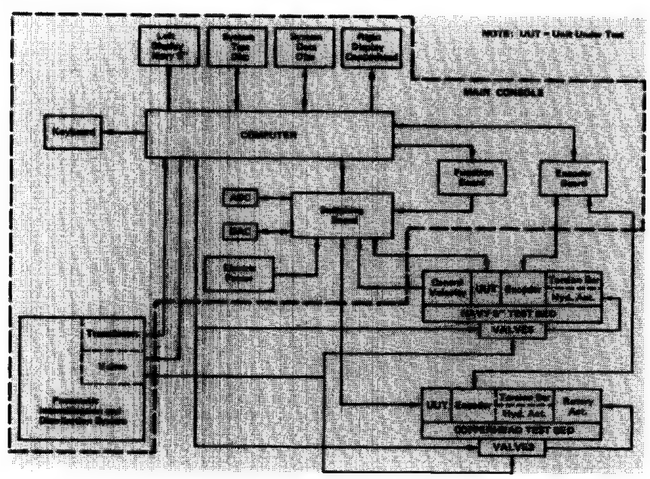


Figure 1

The pneumatic intensification and distribution system includes an intensifier, multistage valving, pressure regulators, high pressure gas container simulator volumes, pressure and temperature transducers, and pressure gages. It has internal feedback systems to control the simulator volume pressures; however, the pressures and temperatures of the control volumes are monitored by the computer.

Trouble Shooting Simplified

The computer, power supplies, and input/output devices located in the upper half of the main console include an Intel iSBC 80/30 (see Figure 3) with 64K of memory, 54K of which is available for 'BASIC' commands. Of the remaining memory, 4K is PROM used for the 'Bootstrap' function, 4K for ADC/DAC control, and 2K for special machine code programs.

Three custom wire wrap boards augment the computer: the encoder, function, and switching cards.

The encoder card provides the interface between the optical encoders located on each stand and the computer. The function generator card contains the alpha numeric display driver circuits and the sine wave generator. The function of the switching card is to be the control switching point for all signals.

Signal generation and measurement sources are common to both stands but selected by energizing reed relays under computer control. This permits maximum flexibility and eases comprehension and trouble shooting.

Test Beds Adaptable

Each test bed contains only those devices relevant to the testing of the system for which it was designed. However,

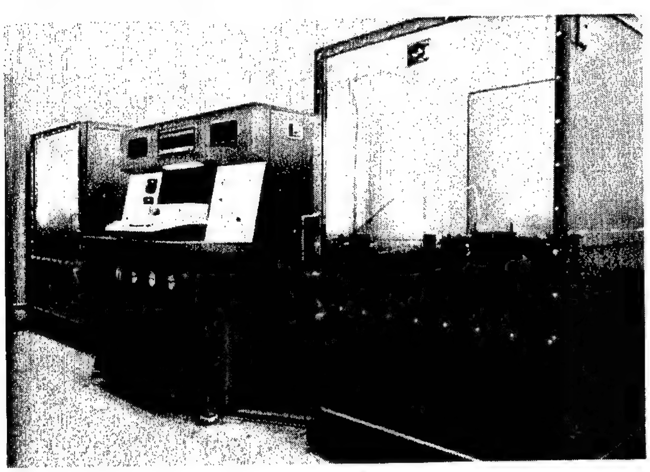


Figure 2

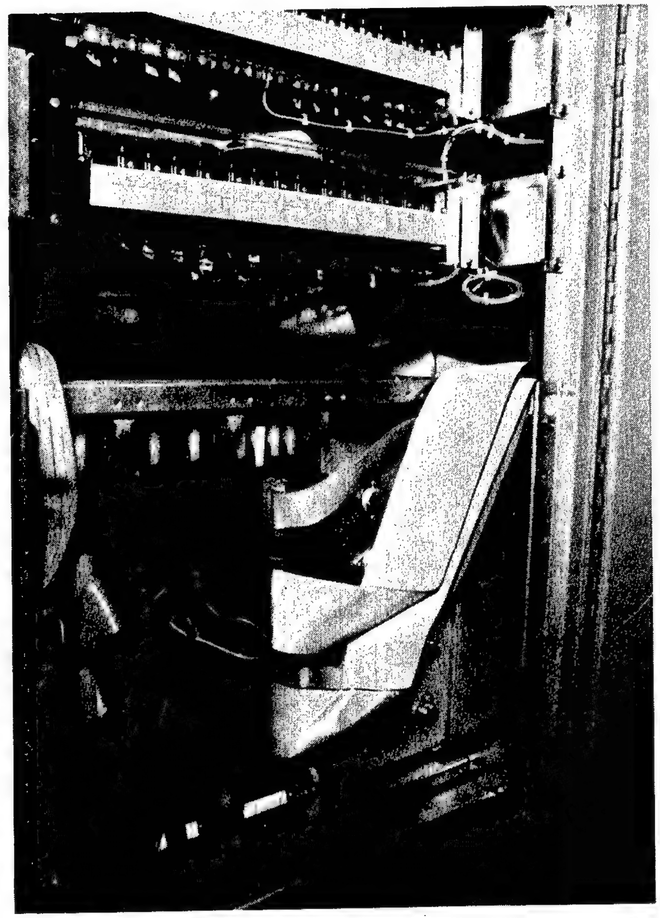


Figure 3

either test bed could easily be modified to accept another system of similar design.

The two test stands accommodate different control sections simultaneously. Therefore, while one unit is being tested, a different unit can be loaded or unloaded on the other test stand.

Each test bed is housed in a steel safety enclosure, on castors so it can be easily pushed back, exposing the interior for routine maintenance and repairs.

Located on top of the Copperhead test bed are four torque simulators and the high pressure pneumatic line which mates to the control actuation system via a quick disconnect fitting. One of the Copperhead torque simulators is shown in Figure 4. At the extreme left is the universal coupling device which connects the control actuator output shaft to the torque simulator. The adjacent protective housing contains the optical encoder used to measure the angular deflection of the actuator output shaft.

The cylindrical mass is the inertia trim weight, and the pulley/timing belt configuration drives the encoder. The housing at the extreme right contains a pneumatic rotary actuator used to set constant clockwise or counterclockwise torques on the control actuation system. Gears are used to transmit the torque output of the rotary actuator to the control actuation system. A torsion bar supported by bearings extends between two housings. The two inner housings contain the hydraulic actuator and mechanism used to clamp the torsion bar. The torsion bar clamps are continuously adjustable along the length of the torsion bar. The Navy 5 inch test bed is similar, but only two torque simulators are required (see Figure 5).

Software Expedites Program

Memory, and timing constraints were a dominating influence during the development of the necessary software. Variable names were limited to one or two characters. The tests themselves work almost exclusively with 8, 12, and 16 bit integer values that correspond to the native units of the hardware. Conversion to and from engineering units was set up to be performed in the PARM and PRINT routines, where memory and time contraints do not present a problem.

PARM 7 and PARM 8 routines maintain the programmable parameters which are used by TEST 7 and TEST 8 (Copperhead and Navy 5 inch verification test programs, respectively). The results of a test are written onto a data diskette for archival and PRINT 7 (Copperhead) and PRINT 8 (Navy 5 inch) produce formatted printouts of the results (see Figure 6). Figure 7 lists the tests included in TEST 7 and TEST 8.

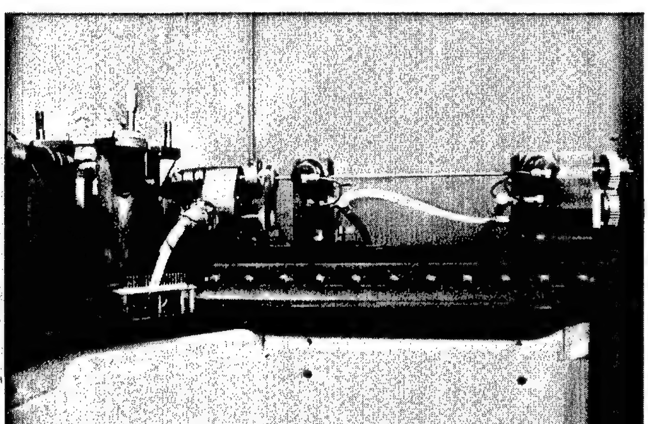


Figure 4

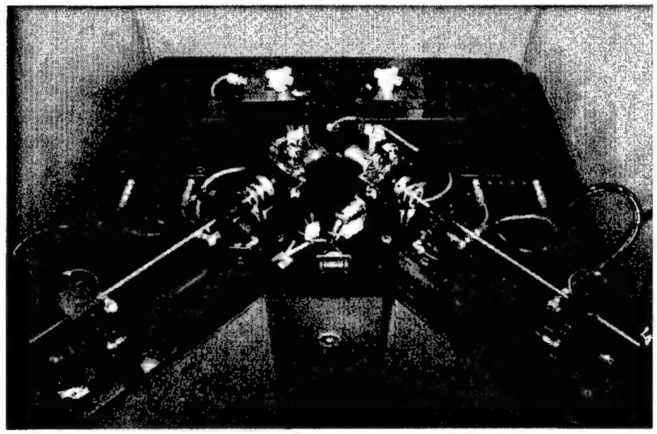


Figure 5

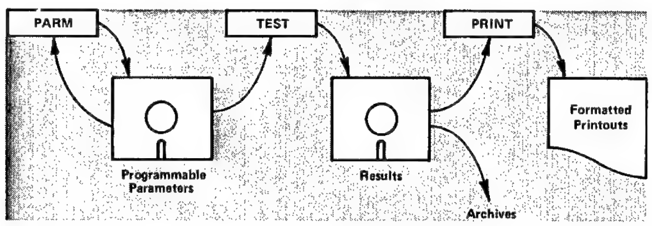


Figure 6

Copperhead	Navy 5 Inch
Test 7	**Test 8**
• Shaft Lock Backlash	• Duration/Duty Cycle
• Potentiometer Null	• Null Offset
• Shaft Rotation	• Shaft Rotation
• Shaft Phasing	• Shaft Phasing
• Stall Torque	• Slewing Velocity
• Angular Rate	• Limit Cycle
• Position Gain	• Position Gain
• Frequency Response	• Frequency Response
• Step Response	• Cutter Resistance
• Duration/Duty Cycle	• Canard Deployment
• Shaft Lock Activation	
• Cutter Resistance	

Figure 7

After obtaining his B.Sc. and Dipl.-Ing. degrees in Mechanical and Electrical Engineering from the Technion, Israel Institute of Technology, Professor Moshe M. Barash was active in engineering design and research in Israel from 1947 to 1955. He received his Ph.D. degree in Mechanical Engineering from the University of Manchester, England. From 1956 to 1963 he was a faculty member of the Department of Mechanical Engineering at the University of Manchester Institute of Science and Technology. He joined the Purdue faculty in 1963 as an associate professor and became a full professor in 1971. Dr. Barash has extensive experience in industry and non-university research in several fields, including design of complex machines, instruments, control systems, and production processes and tools. Since 1963, he has worked in the area of computer aided manufacturing. Professor Barash became Director in 1975 of a 5 year program funded by the National Science Foundation to delve into the applications of modern manufacturing technologies. He has written over 50 publications and journal articles in the past 10 years. His memberships include American Institute of Industrial Engineers, American Society of Mechanical Engineers, American Society of Engineering Education, American Society of Manufacturing Engineers, American Society for Metals, Sigma Xi honorary society, and the New York Academy of Science.

System Models Verified

Rational Design Increases Output

Researchers at Purdue University have developed reliable methods for optimal design and efficient operation of computerized manufacturing systems (CMS)—methods that are leading to improved productivity for automated machining operations. For example, Caterpillar Tractor Co., after investing about $37,000 in software to apply results from the Purdue program, realized a 17 percent productivity increase for a complex system used to fabricate automatic transmission housings. With results like these, the mathematical modeling tools developed at Purdue now are finding widespread use throughout the machine tool industry. Likewise, interest in computer simulation techniques developed in the Purdue program is growing.

Through their extensive investigations of CMS planning, the Purdue research team has developed methods for automatic process selection and planning, mathematical modeling, detailed CMS simulation, scheduling, and economic analyses. Applying these tools, the systems designer can

- Establish machining content and identify basic machine tool elements for particular mixes of parts
- Evaluate basic properties of chosen system configurations and operating strategies
- Analyze specific system designs and detailed operating rules.

The result is a machine tool system that fully integrates and utilizes all of its automated elements. Beyond the potential for increased productivity, availability of these methods should help overcome management reluctance to adopt computerized manufacturing systems. This will speed the introduction of these systems and allow industry to take full advantage of their proven potential.

Boosts NC Tool Use

Computerized manufacturing systems came into vogue around 1970 as a means to automate the production functions surrounding numerically controlled (NC) machine tools. These tools, introduced commercially in 1955 with great promise, have been slow to catch on and still account for less than 4 percent of the machine tools in operation. A primary reason for this slow development has been the inability of production management methods to fully

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturing Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

utilize the potential of the tools. It is difficult to justify their cost when they sit waiting for metal to cut a large part of the time.

The computerized manufacturing systems—also known as flexible manufacturing systems, Variable Mission Systems (proprietary name of Cincinnati Milacron), OMNILINE (proprietary name of White-Sundstrand Machine Tool), and Versatile Manufacturing Systems—were designed and introduced to overcome this problem. These integrated facilities consist of NC machine tools, automatic material handling systems, automatic storage systems, automatic inspection devices, and other auxiliary devices, all controlled by an on-line computer. Their potential to step up productivity cannot be overestimated. Some 75 percent of all machinery and complex metal products are manufactured in batches rather than in large numbers that justify the use of mass production techniques. Computerized manufacturing systems, which are in fact automated job shops, represent the most advanced batch manufacturing mode known today. But these systems, too, have failed to win the acceptance that was expected.

Meets Analytic Need

Management has been reluctant to implement the computerized manufacturing systems because of the large capital investment in equipment and the system complexity, which demands very detailed analysis in the design stage if anything approaching the potential efficiency is to be obtained. Necessary analysis of the complete production function of these systems involves an overwhelming number of variables. Without proper planning tools, it quickly becomes pure guesswork. Thus, widespread CMS introduction has hinged on development and demonstration of a rational methodology for optimal design and operation—a methodology now available through the efforts at Purdue.

Purdue's work, under a National Science Foundation Grant, is being conducted with the active cooperation of the Caterpillar Tractor Company, the Ingersoll-Rand Company, and the White-Sundstrand Machine Tool Company. The study centers on systems for the manufacture of box, bracket, plate, and other irregular shape parts. However, many of the methods are of a general nature and are also applicable to turning operations to produce parts such as shafts.

Interfacing Programs Applied

The basic procedure for CMS design is shown in the simplified flow chart in Figure 1. When the parts to be manufactured have been identified, computer software systems, called Unit Machining Operations, are applied to determine machining content, the required machine characteristics, and the number and type of machines. Two separate, but interfacing, computer programs are used. COFORM (Coding For Machining) describes all features of the surface to be machined. APPAS (Automatic Process Planning and Selection) gives all the processes, including their parameters, with which such surfaces can be produced.

COFORM can describe practically all surfaces encountered in parts of the shapes mentioned above, classi-

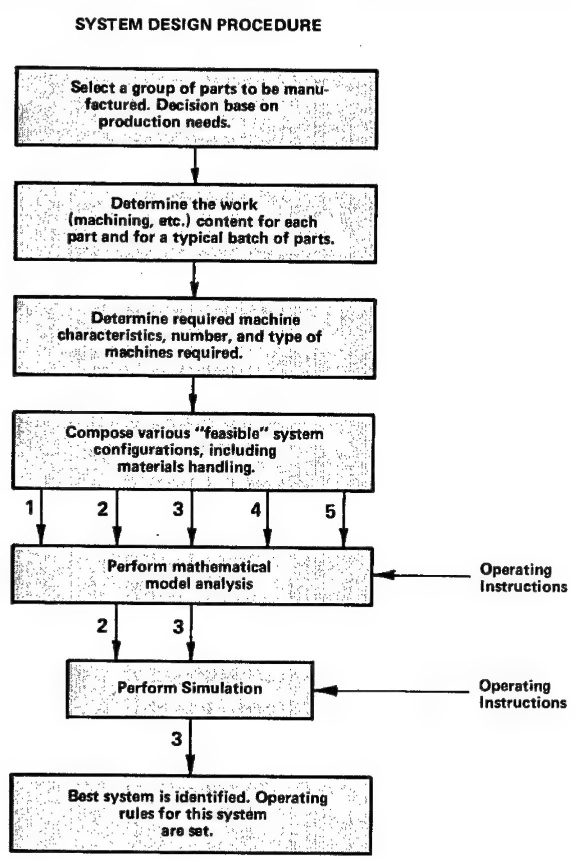


Figure 1

fying them as holes, planes, recesses, grooves, and slots and including material properties, dimensions, tolerances, surface finish, and other attributes. For example, the description of a cylindrical hole would include the part material, diameter and length of the hole, accuracy, and surface finish. A typical hole, with its coded description, is shown in Figure 2. Other codeable surfaces are illustrated in Figure 3.

COFORM output is automatically entered into APPAS, which analyzes each surface, matching values of attributes against process capabilities. As a result, all machining stages for each process are automatically planned; APPAS output specifies tools, feeds, depths of cut, operation time, maximum spindle travel, torque, axial forces, and horsepower for each step. Tool life and cutting force equations are built into the program.

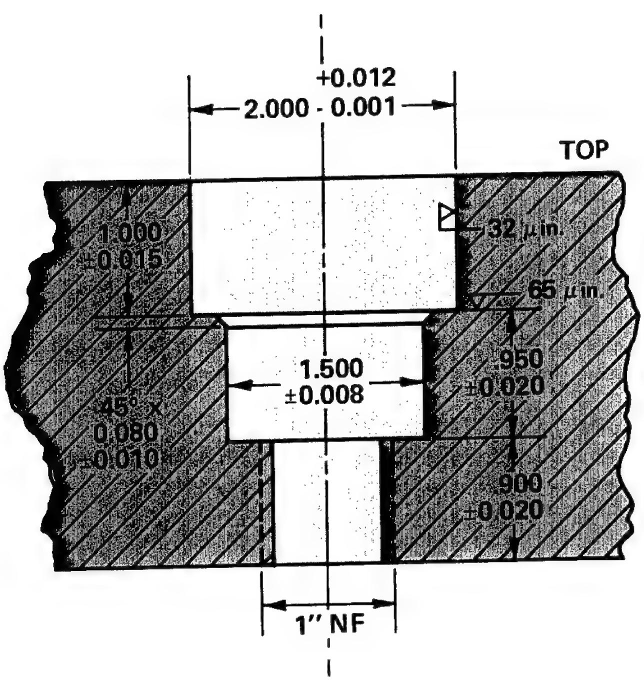


Figure 2

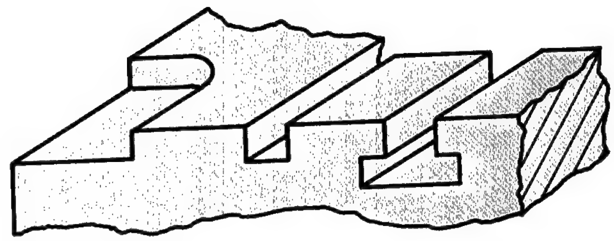


Figure 3

Select Optimum System

APPAS output lists all feasible processes for making each encoded surface. From this, the system designer can select suitable machine tools and compose a number of feasible CMS configurations, including handling and inspection operations. To determine which of these systems are best in terms of given requirements—e.g., minimum productive capacity, maximum cost, sensitivity to partial breakdown, ability to accommodate new products—a number of mathematical models were developed.

First, as suggested in Figure 1, a model is used to select the most promising configuration. This model uses relatively simple operating instructions about machine scheduling and loading. Detailed simulation techniques are then applied to these promising configurations to identify the optimum system. This analysis, in much greater depth, requires considerable information about system operation. If no system is found to be satisfactory in either the modeling or simulation stage, new systems are composed and the process is repeated.

Queuing Networks Modeled

An important factor in determining productive capacity of a CMS is the degree of internal congestion as parts are fed to different workstations. Accordingly, the mathematical model developed for initial system analysis treats each system as a network of queues.

Called CAN-Q, the model represents the system as a set of work stations (e.g., machines, inspection positions) and a transportation mechanism, as illustrated in Figure 4. Workpieces circulate through the system, queuing where necessary, and eventually reach a final load-unload

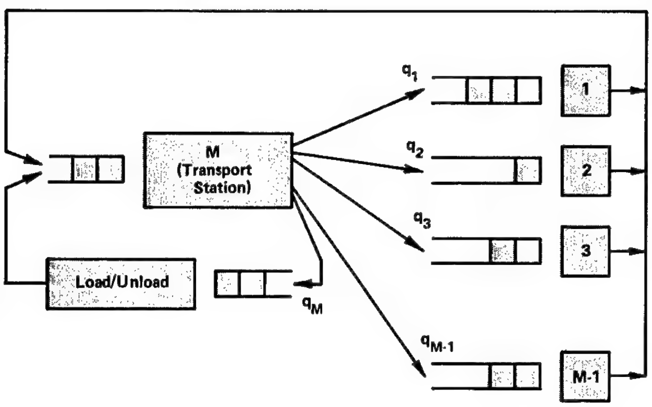


Figure 4

station where the finished workpiece is replaced by a raw casting. Parameters of the model are a set of routing probabilities or visit frequencies (q_1 in Figure 4), the mean processing times for each station, the number of servers at each station, the mean transport time, the number of carriers, and the fixed number of workpieces in the system.

Immense Task Simplified

Applying these parameters, along with some assumptions about queues, the designer can calculate an exact equilibrium probability distribution over all possible states of the network. From this, such values as machine utilization, average queue lengths, system production rate, and mean production time are derived. In obtaining these values, the model can deal with cost or priorities associated with different part types. The form of the model permits these computations to be performed very efficiently, despite the immense number of possible network states.

This efficiency is due in part to several simplifying assumptions made at the outset, some of which were clearly unrealistic. The intent was to relax these assumptions as the model was developed, making it more realistic. However, when compared to detailed simulations, results have proven remarkably accurate and the assumptions have remained in place. The model is considered a reliable tool for estimating relative effects of various design decisions. CAN-Q has also been applied to modeling assembly operations, determining optimal batch size, assessing failure impact, comparing alternative system layouts, and optimizing part mix.

Model Broadly Implemented

Purdue has programmed several versions of CAN-Q and has supplied it to more than 100 major companies and universities. Originally written in FORTRAN and BASIC, the program was also implemented on the Hewlett-Packard HP-67 and HP-97 and on the Texas Instruments SR-52 and SR-59 programmable calculators. Although the later versions are somewhat limited in capability, the advantages of complete portability and immediate access are important to engineers in the field. A second generation FORTRAN version is more convenient than the original and offers additional capabilities that are useful in sensitivity analysis and system optimization.

Actual NC System Simulated

Development of a detailed simulation program for final system selection was based on investigations of an actual integrated DNC (direct numerical control) system, built by Sundstrand and installed at Caterpillar to produce automatic transmission housings. This DNC system consists of four five axis machining centers, three four axis drilling machines, and two vertical lathes, which are fully integrated with a material handling system and a coordinate inspection machine. It is controlled on a realtime basis by a remotely located Digital Equipment Corporation PDP 11/20 computer and supporting equipment.

The machines, located on either side of transport rails, are serviced by two automatically controlled tractor type transporters, each equipped with two cross traveling shuttle mechanisms. The shuttle cars also deliver parts to the inspection machine. Layout of this system is shown in Figure 5. Operation revolves around the 16 station load-unload area, which also provides some in-process storage.

Purdue researchers observed the operation of this system over an extended period and discussed it at length with the designers. Based on the understanding gained, they developed and verified an initial detailed simulation program, called CATLINE, which was written in FORTRAN/GASP IV. This program was used as the basis for

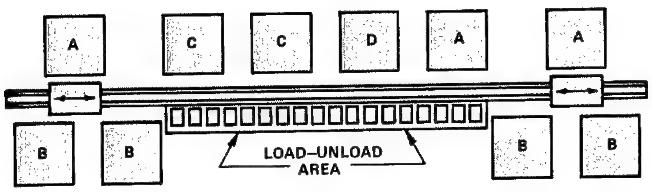


Figure 5

computer experiments to evaluate the effect of material flow, scheduling strategies, and the system's physical configuration. The results of the experiment, along with other results from the CAN-Q model and Caterpillar's engineering design judgment, were used to modify the CMS operating procedures and physical configuration. As noted, these changes have increased productivity of the system by about 17 percent. At the same time, the simulation model was refined.

Generalized Simulator Expands Capability

Applying this experience, a more general purpose CMS simulator, named GCMS, was designed and coded, again in the FORTRAN/GASP IV framework. This model provides a much more robust modeling tool than the CATLINE model. For example, GCMS can simulate different material handling systems, such as conveyors, unidirectional carts on ellipsoídal tracks, or bidirectional carts on one track. It can also simulate malfunctions of machines, carts or conveyors, and tracks and then test various procedures for handling these malfunctions.

The GCMS simulator was used to model the Caterpillar system, as well as two other existing flexible manufacturing systems. One of these was the conveyorized CMS built by Sundstrand for the Ingersoll-Rand Company. The other was built by Kearney and Trecker for Rockwell. Both are substantially different than the Caterpillar system.

Application of the simulator to the Ingersoll-Rand system was relatively straightforward and did not require any program changes or extensions. In this case, the model was used to simulate increased daily production schedules, revised part mix, and revised maching assignments. Simulation results showed logical and anticipated changes in the performance measures.

In order to accurately model the Rockwell line, the 20 basic GCMS subroutines were augmented with user written programs for introducing parts into the system and for moving carts. The simulation results were compared to simulation data on the same system provided by Kearney and Trecker. Output statistics as well as program traces for the two sets of results were similar.

Data Base Added

In order to improve the utility of GCMS, a data base interface was developed to:

- Simplify data input and modification by providing users with clear forms
- Maintain specification data so that both error correction and design changes are easily performed
- Provide a basis for design documentation and for a decision support system.

The basic elements of the data base software include eleven forms, an input drive that processes data punched from the forms and stores it in the data base, and an output drive that extracts data and structures it in the strict format and sequence required by GCMS. The data base interface programs were tested and implemented successfully on several different CMS facilities with significant reduction in user effort.

Second Simulator Designed

Another effort to model and simulate the Ingersoll-Rand CMS was made using Q-CERT, an established, high level network simulation language. The model, designated IRHMC, was developed with a variety of user functions to study several fundamental design and control issues related to a DMS. These issues include:

- **The Part Mix Problem:** Given part production requirements, which parts should be introduced into the system in the same workday?
- **The Part Flow Problem:** Given a part-type mix, how should individual parts be sequenced into the system?
- **The Process Selection Problem:** Given alternative process plans in the CMS for a part type, which particular plan should be selected for an individual part in order to satisfy the system?

Analysis of these issues revealed that the particular operating rules that are applied significantly impact the productivity of the CMS.

These two models represent two types of simulation procedures—the discrete event and process interaction approaches—which were compared using the modeling efforts and experiences obtained during the course of Purdue's investigation. One conclusion from this comparison was that, while both simulation procedures can quite faithfully represent physical configurations of CMS's, the graphical representation frameworks of the process interaction procedures fall well short in their ability to represent operational control algorithms. A second conclusion is that a judicious combination of the two simulation procedures can be used to quickly and effectively investigate a wide variety of proposed system modifications in any of the preliminary design, detailed design, construction, and operational phases of the system life cycle.

Decision Making Assistance

Purdue has also developed a production decision support system (PDSS). This software module assists the production decision maker in controlling and running a complex CMS facility.

For the PDSS, a computer program called analysis system was developed and coded in FORTRAN. This program employs the GCMS simulator as the basic framework. It can analyze the effects of a variety of production control techniques on CMS performance and provide the user with results, such as fabrication order status, production schedule, manufacturing performance, and alert information, that are useful in the decision-making process. In addition, a preprocessor was developed for transforming the system structure data from a simple format free form for the user into a specially formatted form for the analysis system program.

Finally, a physical model of a CMS similar to Caterpillar's DNC line is in an advanced stage of development. This model wil be used to study relationships between the computer control system and the physical design of the facility.

Economic Analysis Possible

The analysis techniques developed for SMC can be extended to include economic criteria and to evaluate the tradeoffs between CMS cost advantages and capital requirements. A CMS provides important economic and productivity advantages over less flexible and less controllable forms of manufacturing. The increased flexibility of a CMS is particularly advantageous in the short run for small batch production of mixed parts on the same system and in the long run for changing part specifications and volume requirements. The increased controllability of a CMS is particularly useful in synchronizing the flow of parts and tools over a greater part of the total production cycle, in maintaining greater and more uniform dimensional accuracy, and in stabilizing production during design and schedule changes. These advantages result in lower direct labor requirements, lower in-process inventories, greater machine utilization, shorter lead times, and improved quality control. On the other hand, the changeover to a CMS requires high initial capital investments and more intensive use of facilities, training in new labor skills, organizational changes, and the use of better planning methods by management. Analysis of the tradeoffs between these advantages and requirements is vital to rational decision on CMS use. The Purdue program simplifies that analysis.

In this analysis, simulation methods like GCMS and Q-CERT and stochastic network models like CAN-Q are used to estimate how the output capacity of a manufacturing system changes as the various components of the system are increased or improved for a known cost. These data are used to develop cost-vs-output curves for a given part or product mix. By comparing these curves for different types of production systems, it is possible to identify breakeven points where a particular type of system is economically preferred over other systems for particular products or product mixes. Furthermore, such data can be used to determine the best way to expand CMS capacity for long run conversion or growth programs. By varying the cost parameters used in the analysis, it is possible to anticipate the effect of changes in the economic climate or in the cost of CMS hardware.

In order to demonstrate this approach, a computer program called CAN-Q-COST was written which extends the CAN-Q model to include labor requirements, wage rates, cost of equipment, required rates of return, and shift patterns. The program begins with a minimal size system for a particular product mix and systematically expands the output rate by incrementally increasing the capacity of bottleneck stations. For each output rate, the program gives the cost per year, cost per hour, and cost per part broken down into its labor and capital components. It also shows how the utilization of capital and labor changes with the size of the system.

Inexpensive Research Tool

Mini Flexible System Versatile

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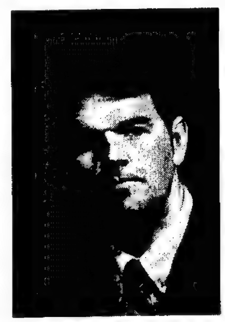

A miniature flexible manufacturing system (MFMS) being developed at Virginia Polytechnic Institute and State University (VPI) provides a versatile, relatively inexpensive tool for research in control system design and analysis. With costs of full scale equipment for such research prohibitive, systems of this nature present an economical way for university researchers to contribute vital development efforts in this important area.

In addition, the miniaturized approach offers an appealing tool for those designing automated systems. Because the elements are easily moved and rearranged, designers can use the MFMS to analyze various layout arrangements, something now done only with analytical models whose validity remains uncertain. The designer can also develop and evaluate software for control of full scale systems on the MFMS. Once proven on the subscale system, software can be transferred directly to the manufacturing process.

Although still lacking one major element, VPI's MFMS is already proving its worth as a research tool. For example, VPI researchers are now using it as a testbed in two programs—one to develop a CAD/CAM (computer aided design/computer aided manufacturing) software system, the other to develop hierarchical control of a flexible manufacturing system (FMS).

Industrial Support Given

When fully arrayed, the system will include three four axis milling machines, a robot part transfer device, an automated storage and retrieval system (AS/RS), and a series of conveyors connecting the AS/RS to the robot load and unload stations. The AS/RS is still under development, but all other elements are operational.

All system elements are controlled and coordinated by a computer in the same manner as those of a full scale flexible manufacturing system. Cost of the system, which is being built with support from the Society of Manufacturing Engineers Educational Foundation, is under $50,000. This compares to millions invested in full scale systems. Space requirements are about the same as for a small office.

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturiong Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

The MFMS is the hub of a dedicated joint research effort in automated manufacturing by the Industrial Engineering and Operations and the Electric Engineering departments at VPI. The total effort focuses on developing more effective and efficient procedures for manufacturing system design and control and on developing a framework for laboratory test and evaluation of such procedures.

Meets Recognized Need

Since the early 1900's, the United States has effectively pioneered the use of automated manufacturing systems for production of such items as automobiles and appliances. However, the inflexible systems (or transfer lines as they are often called) used in these areas require extremely high annual production and stable product design to offset huge capital costs. Annual production must be in the range of 50,000 to 1,000,000 parts if the systems are to be economically effective. As a result, we see subsystems (or entire systems) dedicated to production of a single component or assembly. Other products would require completely different systems.

More recently, attention has focused on flexible, or programmable, manufacturing systems. With computer control, a single flexible machining system can produce a variety of parts. Annual production to ensure economic manufacture with these systems can be as low as 50-1000 parts depending on the part complexity. Such systems can produce as many as 150 different part types.

But, despite the apparent economic advantages, conversion to flexible manufacturing systems has been slower than originally expected. Industry's reluctance to adopt them is most commonly attributed to:

- Poor understanding of system operational characteristics
- Inability to attain optimal system configurations and control
- Inability to justify system costs.

All of which point to research needs that have not been met.

Therefore, researchers at VPI have developed the MFMS as a research tool to help address each of these issues. Resolution of the issues should mean accelerated use of flexible manufacturing systems in industry with consequent increases in manufacturing productivity and efficiency.

Miniaturization Overcomes Barriers

The miniaturized approach overcomes barriers already mentioned that have retarded university research in the area. Because computer numerical control (CNC) equipment is so expensive and requires so much space, the use of such machines for instructional purposes in university laboratories has been virtually impossible. This situation alone has hindered our understanding of the capabilities of these machines and consequently their acceptance.

A typical full scale FMS consists of four to twelve NC or CNC machine tools integrated by an automated material handling system, such as a robot or a conveyor system. The cost of such a system can range from $4 to 15 million. Its installation and operation may require 10,000 or more square feet of floor space. Based solely on capital requirements, it is understandable that U. S. universities and even industries have not rushed out to obtain them.

Through the scaled components of the MFMS, the manufacturing engineering faculty at VPI hopes to gain a greater understanding of the operational characteristics of full scale systems. The VPI facility presently consists of two different types of four axis CNC machining centers and a three axis robot (programmable parts mover). The milling machines (see Figure 1) are built primarily from aluminum, with some components of other metals. They measure approximately 12 by 12 by 8 inches and can machine parts as large as a 4 inch cube. Linear motion (X, Y, and Z axes) of the machines is constrained by dovetail ways and slides. Stepping motors, which drive lead screws or rack and pinion gear systems, provide the operating power.

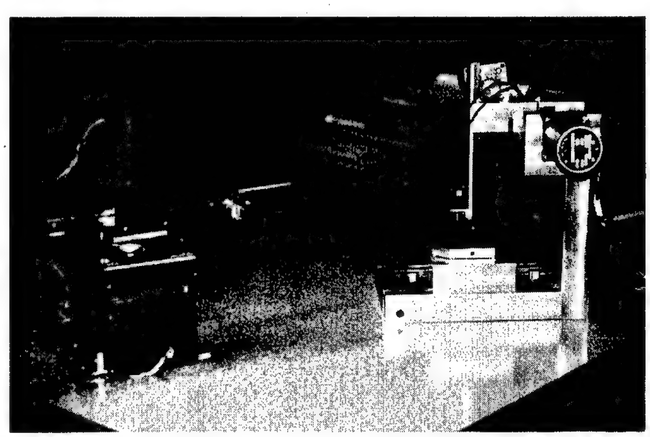

Figure 1

Absolute Positioning Maintained

Each machine has a separate microprocessor that independently controls all four axes. These control units generate a directional signal and a square wave pattern consisting of a fixed frequency and pulse count. For example, the stepping motors currently employed in the system are Slo-Syn motors that produce 45 oz-in. of torque and step 200 times per revolution. The motors drive a lead screw with a pitch of 10 threads per inch.

The robot for parts transfer is seen in Figure 2. Like the milling machines, it is stepping motor controlled by its own control unit. The robot can service machines within a 9.5 inch radius. However, unlike the machining centers, it uses an absolute rather than incremental positioning system. With this absolute positioning system, variations in machine locations can be analyzed quite easily. Figure 3 shows the transfer device servicing a milling machine.

Versatile Research Tool

Although each machine in the system can be operated independently in order to demonstrate process requirements at machine level, the standard operational mode is at the system level. In that mode, a control computer imparts programming information through the microprocessors to each of the machines (including the robot). Once a part machining program is completed, the controller proceeds automatically to the next instruction sequence, be it another part program or a material handling activity. Besides monitoring and controlling the system, the control computer processes the part programs to formulate machine instructions.

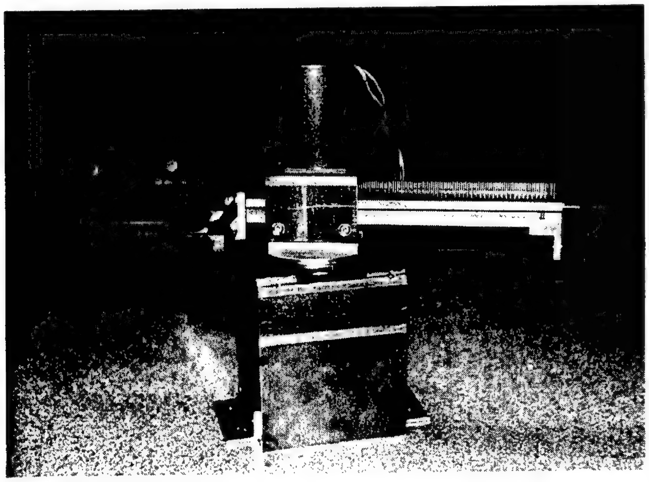

Figure 2

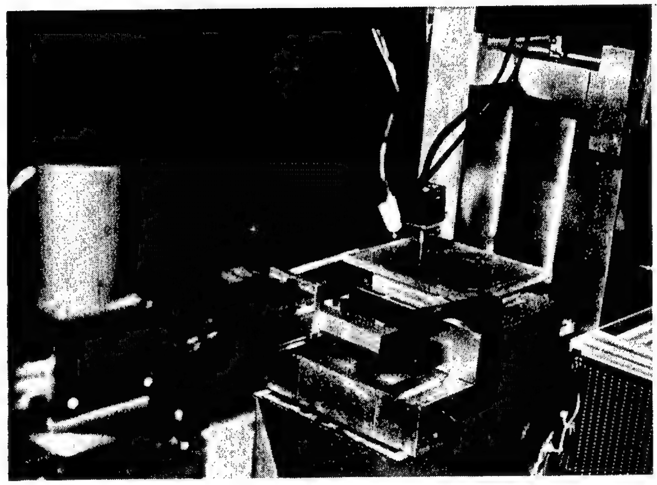

Figure 3

Configuring the system in this manner permits instruction and testing to be conducted at both the process and system levels. Scheduling and sequencing algorithms can be written and introduced to determine their effect on system performance. Similarly, programming changes required to improve system control can be identified.

In the final stage of system development, VPI is constructing and integrating the AS/RS. This element will contain a parts mover, which will operate with stepping motors and controls similar to those of the other system components. It will provide raw, in-process, and finished part storage for the complete system. With its own system controller and inventory management unit, the AS/RS will complete what is envisioned as a miniature automated factory.

Obvious Benefits

The educational benefits of the miniature system are apparent. The complete system cost, less the development expense, should be under $50,000 (this includes two microcomputers and six machine controllers). More important are the minimal space requirements and the ease of reconfiguring the system, which requires only a screwdriver and adjustable wrench.

VPI researchers envision such systems being used as pilot plants in the design of large scale systems. Using these models, the designer can analyze operational

problems, as well as system software, and make necessary refinements before any major manufacturing expense is incurred. When the miniaturized system is carefully designed, the software for a full scale system can virtually be developed in total and then simply transferred from the miniature prototype.

This form of prototyping, which has proven effective for many major mechanical and chemical systems, provides a missing link in automated manufacturing system design. Although such prototype models will certainly not replace analytical models, they can serve a valuable role in enhancing the fidelity of the analytical models and in evaluating the validity of the analytical results.

Two ongoing research activities at VPI, which provide a proving ground for MFMS utility, demonstrate how the system can be applied in research and in production system design.

CAD/CAM Interfacing

VPI's CAD/CAM research is directed toward developing an interface between these two key elements of computer aided manufacturing that will allow integration of all production steps into a fully automated manufacturing process. The interface concept under investigation is illustrated in Figure 4.

This concept divides the design process into two stages—structural design and detailed surface design. During the surface design stage, detailed tolerance, surface finish, and form geometry data are fed to the computer. Using a programmed logic, the computer selects appropriate processes for each surface. Based on the selected processes, an interface routine pulls data from the design data base and transmits it to an automatic process planning routine, which generates optimal machining parameters. The program then estimates machining cost for these processes and parameters. This cost estimate provides a measure of the production efficiency of the design. If the cost is high, the designer might want to change the design.

When design plans are finalized, a process generator of the APT (automatic programming tool) type can read in geometric data and optimal process information. Using these data, the computer will generate the optimal tool path and machine operating instructions. This information can then be transferred to a DNC system to operate the actual production process. Such a system would provide a totally automated production cycle from design to implementation.

Focus on Three Elements

The VPI effort to develop this concept through the CAD/CAM interface focuses on:

- An interactive graphics system for describing surfaces
- Interface with an automatic process planning routine
- Cost estimation.

For cost estimating purposes, a computer software package has been developed and demonstrated.

With this program, the designer can quickly obtain the cost of precision machining (i.e., dimensional tolerancing and surface finish) and integrate it with the design process in two distinct ways.

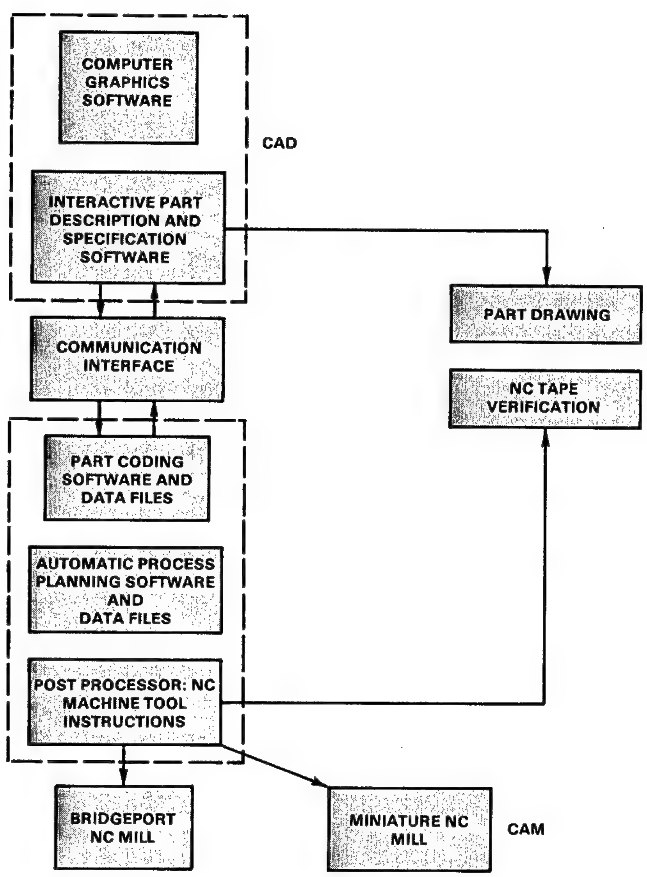

Figure 4

First, part specifications can be evaluated to determine if the designated degree of precision is justified in light of machining cost. Potential design modifications can then be evaluated to effect an acceptable compromise between production cost and part precision.

Second, if the required precision is varied, the manufacturing process (tools, machines, and number of operations) required can vary significantly. Consequently, the machines (and even entire manufacturing systems) required to produce the parts can be dramatically altered. In essence, there is a potential impact on both the variable cost of manufacturing as well as the fixed cost associated with the procurement of tools (and machines). As this concept is developed, the MFMS plays an important role in evaluating the associated software.

Hierarchical Control System Design

In a second program, VPI researchers seek to identify the critical technical parameters that are required to make effective management decisions regarding automated manufacturing systems. These decisions relate to design issues that must be addressed in configuring a hierarchical control system to coordinate and integrate operation of a manufacturing system. The hierarchical approach is consistent with current systems and offers distinct advantages in interfacing to the overall information systems of modern manufacturing firms.

Total integration of a flexible manufacturing system requires a decision structure that can resolve scheduling, sequencing, selection, and process control decisions for machine operation, part transfer and positioning, part and material transportation, and storage and retrieval of parts and materials. However, there are no procedures for making communications system design and operation decisions in a quantitative and integrated manner. Development of such procedures is being investigated as part of this research. The MFMS provides a physical testbed for evaluating the effectiveness and utility of these procedures.

Model Development

This research focuses on the development of both mathematical and simulation models of the hierarchical control system of an FMS. The mathematical model is used to identify the hardware and software requirements and capacities of the control system that yield an ''expected'' optimum in manufacturing system performance (i.e., minimum production time or maximum throughput). Based on this result, a computer simulation model tests system performance and robustness. To simulate actual system operation, such contingencies as lost machine instructions, variability in part mix and production demand, and machine failure are incorporated. Based on results of the simulation analysis, the control system can be further improved and then evaluated on the MFMS testbed.

The significance of a testbed for integrated control system design and operation is particularly apparent at the machine/part transfer interface. Here, interactions of specific process control decisions, part transfer sequencing, and scheduling decisions must be controlled in a prescribed and orderly (although not necessarily optimal) manner for the system to function. Erroneous control information or contingencies that arise in system status but that are not accounted for in the control structure or information process lead to such anomalies as missed processes, machine ''lock up'', and ''system lock up''. These areas of control must be addressed in system design and in a testbed approach that implements and monitors system performance.

Computer Capabilities

In VPI's hierarchical approach, each level of communication is implemented through an increasingly capable computer system. A general approach to implementation that will permit various interconnections is illustrated in Figure 5.

Interfacing and communications within the varying configurations of the MFMS are being developed to permit a complete investigation into the actual ramifications of such issues as:

- Distributed vs. centralized control, hierarchical implementation, and redundancy requirements
- Microcomputer/minicomputer modules, with capabilities for local communications, remote communications, and local control.

VPI will investigate inroads into NC implementation, such as ''smart'' controllers. These investigations will track the rapid growth of the electronic controls industry and will also suggest many new avenues of operational control capability.

MFMS Important Element

The MFMS will enhance this research effort. As noted, unlike full scale systems that are permanently installed, the miniaturized system can be configured in many different layout arrangements. Thus, effects of sorting, merging, blocking, or accumulation of parts mounted on fixture pallets can be examined more fully.

Additionally, the location and size of a buffer storage area and the associated materials scheduling and control issues can be addressed directly. In short, the miniature system will permit virtually the same analyses and control scenarios that a large scale system would. But it will do so much more simply and quickly and at far less cost. The need for excessive abstraction, often required with mathematical and computer simulation modeling efforts, will be eliminated.

The development of a miniaturized physical model and its attendant framework will also resolve some of the issues raised by current mathematical and simulation studies. Although such studies are now used to analyze flexible manufacturing systems, the degree of validity is still a subject of much discussion and research.

The modeling task can be better accomplished by developing the software needed to physically operate a miniature system and to incorporate control strategies currently used in industry and other strategies proposed as a result of mathematical and simulation studies. With appropriate scaling, this control software should be directly transferrable to an actual system. The economic benefit of this transfer alone is significant. And, it is only one aspect of the total benefits to be realized from expanded research, improved design procedures, and implementation of more efficient manufacturing systems.

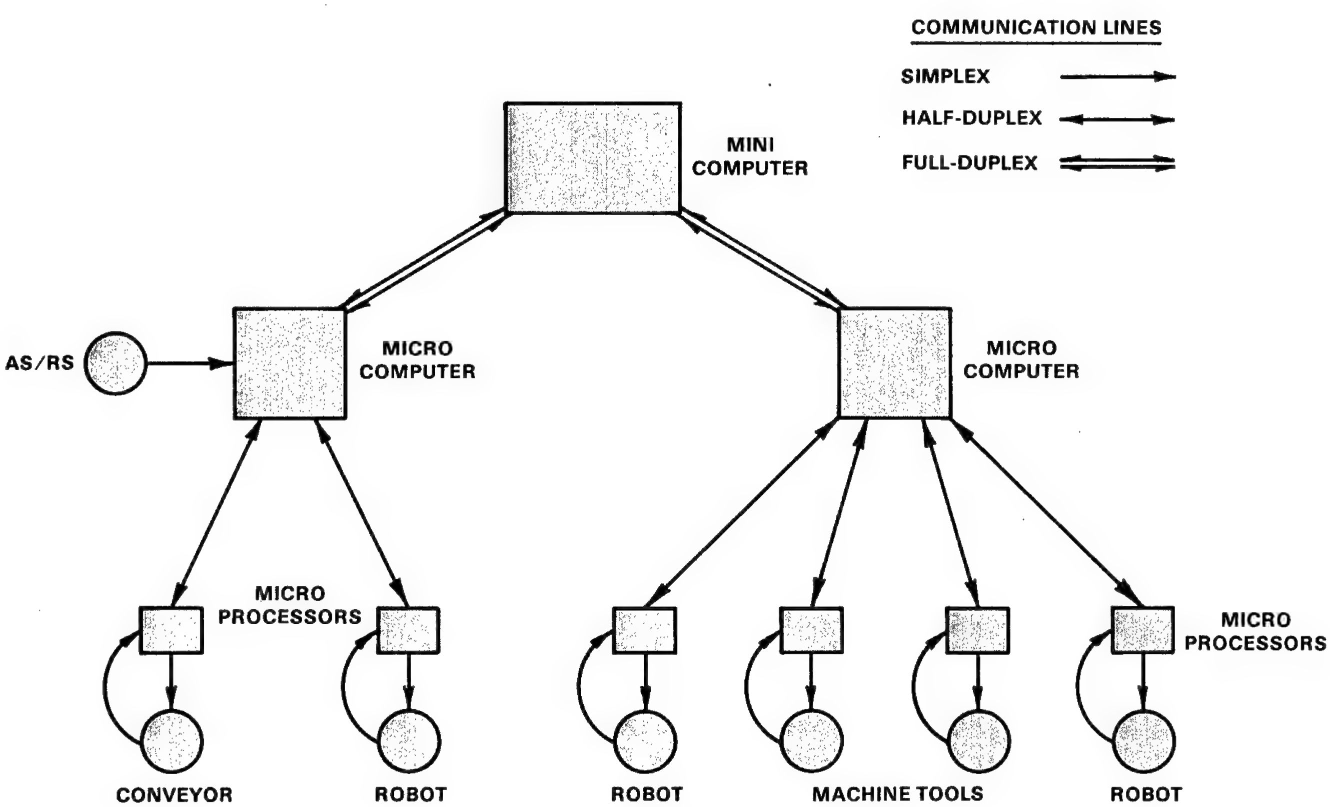

Figure 5

One Piece Program Pays Off

Large Titanium Compressor Cast

MICHAEL D. ROSS is a Senior Materials Engineer with the Pratt and Whitney Aircraft Group, Government Products Division. During his nine years in the Casting Development Group, Mr. Ross has been involved in numerous advanced casting development programs including development of single crystal turbine hardware. Along with casting development work, Mr. Ross currently is conducting studies into rejuvenation and repair of service retired turbine hardware.

No Photo Available

During the past decade, titanium castings have been used for small static components such as brackets, connecting links, and hinge beams in gas turbine engines. These castings have been so cost effective and dependable that the Air Force funded a program to establish manufacturing processes for larger titanium castings for engines in the 25,000 lb thrust class. The result was a large one piece intermediate compressor case casting which cost 20% less than the original wrought and fabricated design and conserved both wrought and raw materials.

As the prime contractor, Pratt and Whitney Aircraft Group's Government Products Division designed the Air Force program to:

- Produce a large, complex fabricated component as a casting.
- Utilize both separate component and integral casting approaches.
- Investigate scrap reclamation as a method of further cost reduction.
- Verify mechanical properties of all casting approaches.
- Assess the need and/or desirability of Hot Isostatic Pressing (HIP) for large titanium castings.
- Evaluate the effectiveness of chemical milling as an excess weight removal process.

Component and Alloy Selection Clear Cut

The intermediate compressor case (Figure 1) for the F100 turbofan engine was the logical choice for a single piece titanium casting because of its high fabrication cost, complexity, and low material utilization. The case has four major subcomponents: the outer ring, the struts, the inner ring, and the splitter rings. The outer ring has a maximum outside diameter of 40 inches and includes features such as top engine mount lugs, a gearbox adaptor, six ground handling lugs, a boroscope boss, and two oil tube bosses. Of the eight struts, one is oversized to allow the starter shaft to connect the core rotor and the external starter gearbox. Concentric with the outer ring and attached to the struts, the splitter separates air for the high pressure compressor and the outer engine duct. The 19 inch inner ring contains and supports the 2-3 crossover bearing housing.

The intermediate case is fabricated from wrought Ti-6Al-4V alloy. The inner and outer rings are machined from forgings. The splitter ring is fabricated from rolled rings and sheet stock and the entire assembly is welded together. Over 1100 lb of titanium is machined into a case weighing 60 lb. Also, approximately 250 lb of the machining scrap is nonrecoverable ECM sludge.

The alloy chosen for the compressor case casting was the most commonly and effectively used alloy for titanium castings—Ti-6Al-4V. It combined strength with good ductility and had a controllable liquid metal reactivity. Also, past experience had shown it to have very good response to hot isostatic pressing.

Design Modified to Facilitate Casting

In order to optimize castability and cost effectiveness, modifications to the wrought design were closely coordinated with the casting subcontractor—Precision Castparts Corporation of Portland, Oregon. The inner and outer wall dimensions of the compressor case were increased and connected by gradual tapers to larger flange areas (Figure 2) to control solidification and minimize

NOTE: **This manufacturing technology project that was conducted by Pratt & Whitney Aircraft was funded by the U. S. Air Force. This article has been based on a paper presented at the 1980 Tri-Service Metals Review Program sponsored by the Metals Subcommittee of MTAG.**

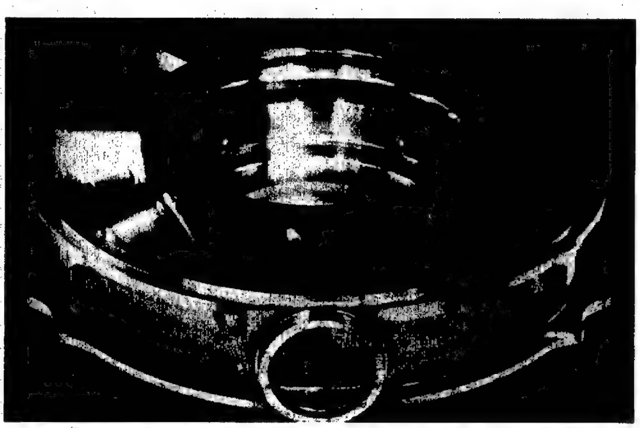

Figure 1

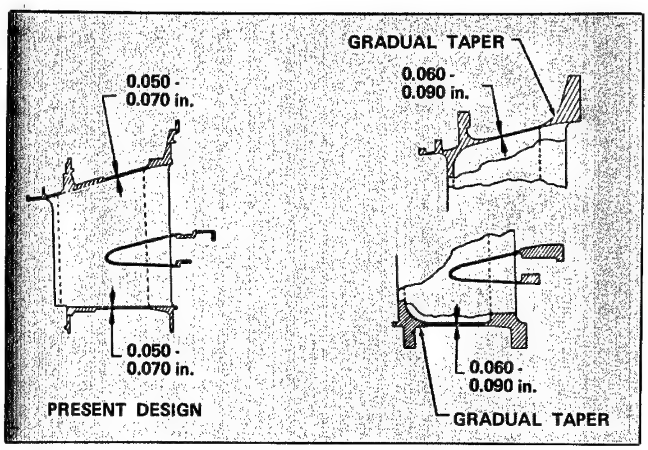

Figure 2

shrinkage. Similarly, the splitter walls were thickened and the aft splitter flanges enlarged. Also, undercut areas were increased to simplify the wax pattern tooling and minimize production costs.

Wax Pattern Tooling Design Expandable

Because of the size and complexity of the intermediate compressor case, expandable wax pattern tooling was designed so that an outer ring pattern would be initially produced. This tooling would then be reworked to include the other integral case components. This way, progressive development of the necessary component casting techniques could occur, and a baseline for comparing separate cast components with one piece casting for castability and cost effectiveness could be produced.

The major wax pattern tooling components are illustrated in Figure 3. They consist of a base plate containing eight outer ring and eight inner ring (not shown) die segments, eight two piece strut die segments, and a top plate with eight core boxes and an outside collector ring. The outer and inner ring die segments are moveable along radial glide slots, while the strut dies can be split and removed from the base plate for removal of the wax pattern. The top plate, collector ring, and core boxes seal and contain the lower die assembly along with forming the air path surfaces between the struts.

Additional tooling was required for the inner and outer ring wax chills and soluble wax cores. Because of the thickness of the inner and outer ring flanges, wax chills were used to minimize wax shrinkage and to control dimensions. Figure 4 illustrates the placement of the wax chills within the lower die assembly for the inner ring flanges. Soluble wax cores were used with the wax die assembly to form the internal surfaces of the struts and the gearbox opening. The soluble cores are held by the inner and outer die segments and are surrounded by the strut die segments. After a wax pattern has been injected around the soluble cores (Figure 5) the soluble wax is leached away, preparing a cavity ready for shell investment and subsequent casting.

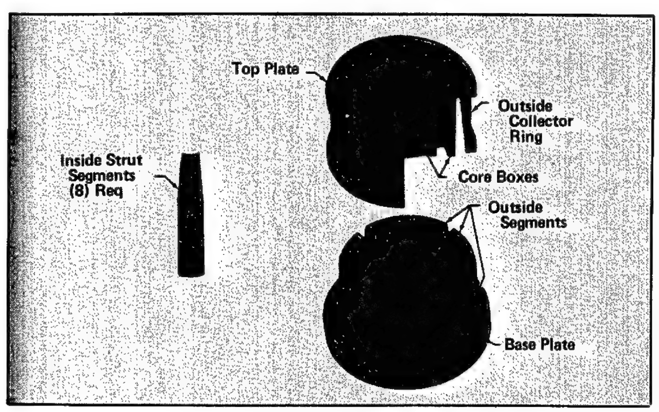

Figure 3

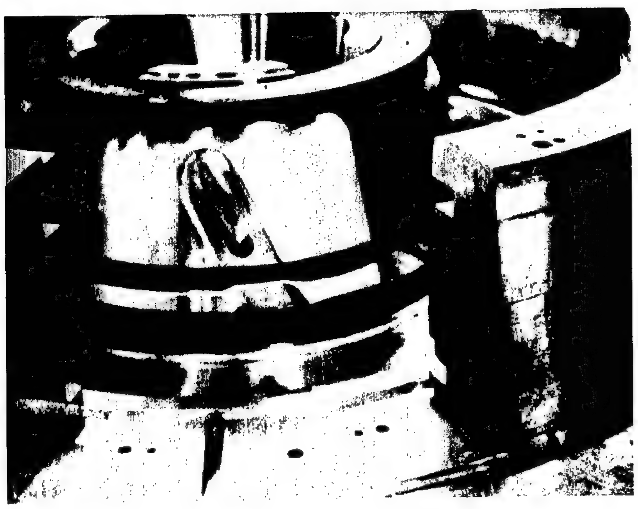

Figure 4

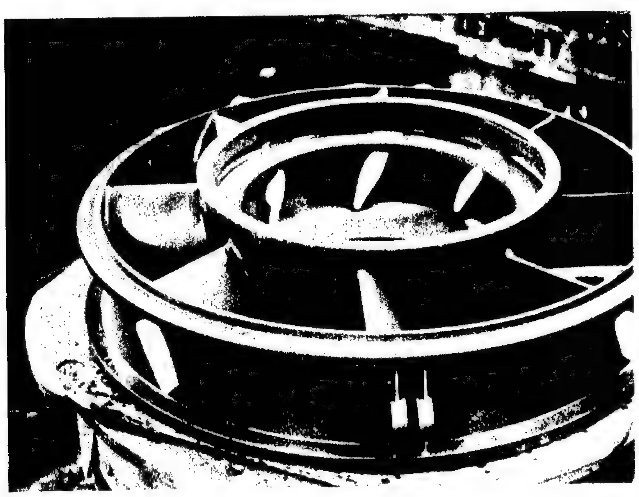

Figure 5

Casting Process Successful

Casting iterations were made in sequence on the outer ring, on a basic integral case without the splitter, and on the inner ring. With each casting iteration a complete series of visual, X-ray, and fluorescent penetrant inspections were conducted to guide the development of the gating for each particular component.

The initial gating design for the outer ring produced the part shown in Figure 6 with large no-fill, gas, and shrinkage areas in the thin wall sections and borderline shrinkage in the thick flanges. By the third casting iteration, the gating had been finalized and produced the outer ring shown in Figure 7 with complete fill, acceptable shrinkage levels, and minor repairable gas porosity.

After the outer ring casting trials were completed, the wax pattern tooling was reworked to incorporate the inner ring and strut die segments to produce a basic integral case pattern without the splitter ring. Again, three casting iterations were made, with the final part (Figure 8) having only one small and repairable no-fill area and acceptable to easily repairable shrinkage and gas levels.

Inner ring wax patterns were cut from basic integral case waxes to produce three inner ring castings. As with the two previous components, the gating was evolved to produce an acceptable casting. With the successful completion of these casting trials, the wax pattern tooling was reworked to machine the cavity needed to form the splitter ring. Additional tooling was also needed for a soluble core in the internal splitter configuration and for a wax pattern chill in the heavy rear flange of the splitter.

Four integral castings were poured with four different gating designs. Each design controlled shrinkage; however, the leading edges of the splitter ring could not be filled (Figure 9). This was resolved by modifying the wax tooling to produce a splitter with a cutout window between each strut to encompass the no-fill areas. A new wax tool was machined to produce a leading edge splitter

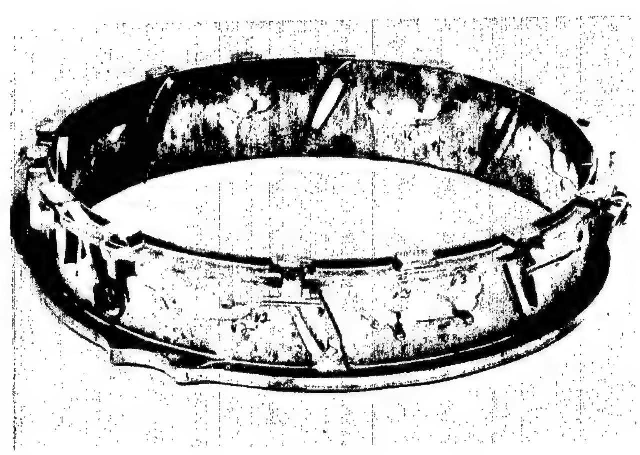

Figure 6

Figure 7

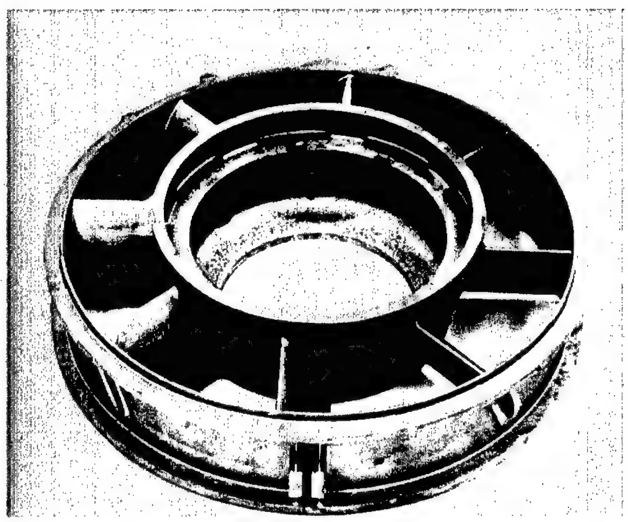

Figure 8

segment which could be cast oversize, fitted to each splitter window, and welded into place. Three out of four integral case castings poured with this abbreviated split-

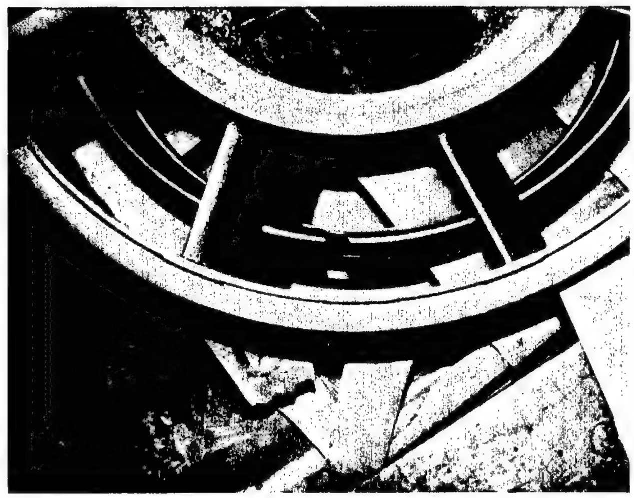

Figure 9

ter design were of an acceptable/repairable quality. This type of casting is shown in Figure 10.

The abbreviated splitter design solved a difficult casting problem; however, it produced an even more difficult welding problem of a highly constrained weld with tight dimensional requirements. The weld attachments of the splitter sections were made, but not without varied degrees of splitter nose and wall distortion in all eight sections.

Hot Isostatic Pressing (HIP) Incorporated

Selected outer and inner rings underwent HIP at 1650 degrees F/15 KSI for three hours. Inspection before and after HIP revealed that all subsurface shrinkage was closed and bonded.

Rejectable subsurface defects surfaced as depressions where—if below minimum allowances—they could be puddle welded and flush ground. This resulted in less casting rework and repair. Measurements before and after HIP showed that dimensional movements were well within the ample tolerances provided by the casting envelope. Alpha case surface contamination was controlled by surrounding the casting with scrap titanium clippings. These clippings served as oxygen accumulaters, limiting alpha case to an acceptable 0.0005 inch that was removed by etch cleaning. It therefore was decided that HIP would be incorporated into the processing of the final integral

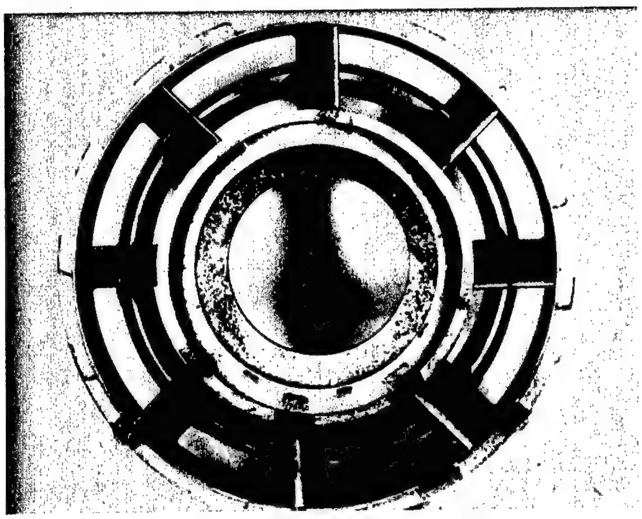

Figure 10

cases because of its benefits in reducing the difficulties and costs of casting repair and finishing.

Chemical Milling Successful But Limited

The increase in wall and splitter thickness resulted in an undesirable weight increase which was costly to reduce or remove by conventional machining. Chemical milling (chem mill), a process used to remove surface contamination resulting from casting and subsequent thermal cycles, was investigated as a cost effective method of removing this extra weight. All titanium parts today have chem mill removal stock incorporated into the wax pattern tooling.

One of the scrap integral castings with the full splitter ring was chem milled to determine the approximate weight loss per surface relationship. Slightly over 1 lb was reduced per one mil of surface removed, which was an effective reduction. However, the degree of weight removal will be limited by the minimum wall dimensions of the casting and can only be consistent on an appropriately designed component with close and repeatable dimensions.

Scrap Reclamation Saves

Using the gating scrap from the outer ring and basic integral castings, a 65% revert/35% virgin alloy electrode was produced at Teledyne Titanium of Monroe, North Carolina by the nonconsumable rotating electrode melting process. This electrode was used to cast the third inner ring casting. Comparison with the virgin alloy inner ring castings revealed only slightly higher gas porosity levels that were attributed to a slightly higher revert alloy oxygen content.

A cost analysis was performed for production quantities of 65% revert/35% virgin alloy remelt stock produced by this method with sufficient quality controls to ensure desirably low oxygen levels. The result was a 2 to 1 cost advantage for the revert/virgin alloy over virgin alloy remelt stock.

Mechanical Properties Evaluated

Extensive thick and thin section tensile, Low Cycle Fatigue (LCF), and High Cycle Fatigue (HCF) testing was performed on specimens machined from each type of component. Separate versus integral castings, non-HIP versis HIP plus annealed material, and virgin versus revert alloy were evaluated. In all cases, the mechanical properties met or exceeded the cast case design requirements with the following results:

- Integral castings exhibited slightly lower tensile properties than separately cast rings.
- HIP processing did not reduce tensile or LCF properties and improved HCF properties.
- Revert alloy casting properties were equivalent to virgin alloy casting properties.

Program Pays Off

Production of large, complex Ti-6Al-4V alloy castings is now within the current "state of the art". In addition to the savings of 20% per casting, gross loss of recoverable wrought material through ECM sludge is eliminated and the raw material buy/fly ratio is reduced from 18 to 8. These improvements will become increasingly valuable as advanced performance and future generation turbine engines are developed.

US Army

ManTech Journal

New Executive Emphasis

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Contents

1 **Comments by the Editor**

3 **Rx for Our Ailing Defense Industrial Base**

6 **Brief Status Reports**

11 **Digital PCB Faults Isolated**

18 **Flexible PC's With Integral Molded Connectors**

26 **Welding Wire Inspected Faster, Better**

28 **University Aid to CAM Research**

32 **Penn State Program Pushes CAM and Robotics**

37 **Composite Bonds Improve Thermal Integrity**

42 **Composite Gimbal Tooling, Fabrication Less Costly**

Inside Back Cover — Upcoming Events

ABOUT THE COVER

Metal foil can be strip cast at a rate of thousands of feet per minute, as seen in this photograph of an experimental run at Battelle's Columbus Laboratories. Quench rates of over a million degrees Centigrade per second refine atomic structures and greatly alter mechanical, physical, and chemical properties. Property improvements and energy saving potential are attracting worldwide attention to this "rapid solidification" research area. In the inset photo, the product of a short (approximately 30 second) experimental strip casting run lies where it fell. In production, the strip is caught and coiled continuously. For further information, contact Mr. Robert Maringer, (614) 424-4314. (Photo by Battelle photographer Bill Weider.)

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Comments by the Editor


RAYMOND L. FARROW

Since the mailing of the last issue of the U.S. Army ManTech Journal, much has transpired in the manufacturing arena covered by this publication. One of the most important events was the 1981 meeting of the Manufacturing Technology Advisory Group, which was hosted in San Diego by the Navy. Achievements outlined there were truly outstanding, and judging from the results of recent budget proposals by the administration, achievements in the future will be even more dramatic.

There's no mistaking the fact that the manufacturing technology effort that the Army has been pushing for more than a decade and a half is having a beneficial impact on our national economy, an impact that has been recognized by the administration in its proposed defense budget. Mantech is going to be a major weapon in the fight to control costs within the limitations of our national economy, and the acceptance of this fact is reflected by the increased funding for manufacturing technology related research and development. As mentioned in the guest editorial by Mr. Richard Kotler of the U.S. Army Missile Command in the last issue of the Army ManTech Journal, manufacturing technology programs also provide several positive steps toward improving our industrial readiness; the new executive emphasis on the programs will expand both beneficial results.

The guest editorial on Page 3 of this issue of the Journal is by Mr. Frederick Michel, Acting Director of the Directorate of Manufacturing Technology, U.S. Army Materiel Development and Readiness Command. Mr. Michel can speak most knowledgeably of our defense industrial base, both from industry's perspective and also the government's view, as he has extensive experience within the Department of Defense and also within the industrial sector. In his present position with the Army's Directorate of Manufacturing Technology, he enjoys a unique overview of the entire Army production readiness capability for which his agency is primarily responsible. We think our readers will find his views thought provoking.

Other items of interest in this issue of the Army ManTech Journal include a pair of articles by Gordon Little of MICOM on the testing of digital printed circuit boards and automated parts handling in fabrication of flexible printed wiring. These will be followed in our next issue by yet another article on one of Mr. Little's projects, the development of new, efficient procedures for termination of flexible printed wiring to connectors. Mr. Little previously was a contributor to the Journal with an article on IR testing of PC boards.

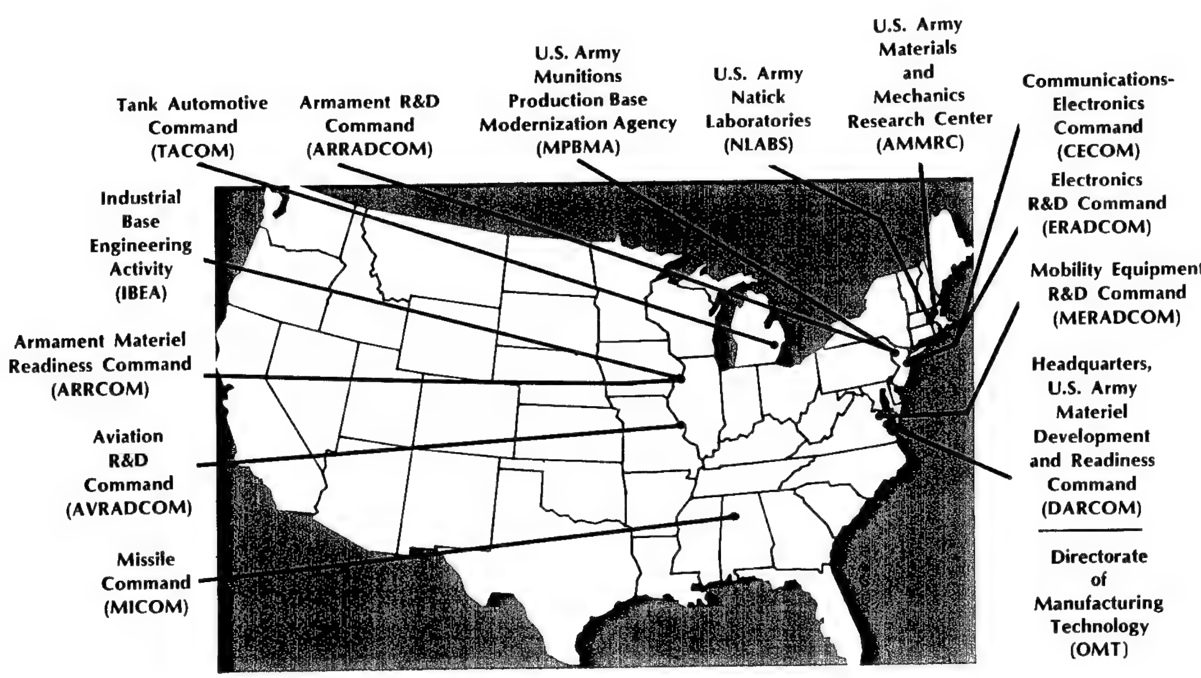
An article on Page 26 about a TACOM project on welding points up a new method of nondestructive inspection for flux core welding wire which is highly reliable, fast, and efficient. With the development of this new technique, automated welding procedures will not be hampered by poor quality welding materials or by supply shortages at high rates of production.

A new development in composite use is highlighted on Pages 37-48 in a pair of articles by Al Kleider of AVRADA, who has been the Project Leader on a multiphase project by Westinghouse to fabricate stabilized line of sight gimbals from these light, strong materials. Not only were the resultant units 45% lighter than the aluminum versions, but rigidity and dimensional thermal stability were as good, if not better, than in the metallic counterparts. Several critical structural difficulties were surmounted during the course of this program, and methods developed to overcome these obstacles will be useful in other applications for these wonder materials in the future.

Readers of the Journal again will become more aware of some outstanding contributions by the academic segment of our national manufacturing effort in this issue, as in the past two issues, with articles on Pages 28 and 32 about excellent training programs at the University of Illinois at Chicago Circle and at Pennsylvania State University. These are reports on presentations made at the 1980 MTAG meeting in Miami Beach and provide both government and industrial managers with information about who is training our new young engineers and where they are receiving specialized training to meet the challenges ahead. Recent testimony before a meeting of the House Committee on Science and Technology indicated a deficiency in our nation's ability to produce the engineers needed to remain technologically competitive with the rest of the industrialized world. We feel that specific programs in manufacturing training deserve the special attention of management personnel.

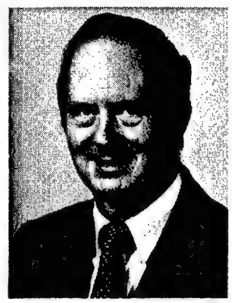
One other note of special interest in this issue of the U.S. Army ManTech Journal is the increased number of briefs of ongoing or recently completed projects starting on Page 6. This is made possible through the all encompassing reach of the modern day computer system. The latter marvel enables our editorial staff to pinpoint projects with summaries of activity and the name and phone number of the main point of contact. We plan to continue this expanded section on briefs, which has drawn exceptional response from readers.

DARCOM Manufacturing Methods and Technology Community



A Sure Cure Available

R_X for Our Ailing Defense Industrial Base



FREDERICK J. MICHEL currently is the Acting Director for the U.S. Army Manufacturing Technology Program. The Directorate is responsible for Producibility Engineering, Design to Cost, Production Engineering, Value Engineering and the Manufacturing Methods and Technology Program, Project Engineering Support, Specifications and Standards, and the Capital Investment Master Plan. He is a member of the Executive Committee of the Department of Defense (DOD) Manufacturing Technology Advisory Group (MTAG) and is Chairman of the CAD/CAM Subcommittee of MTAG. He is also a member of the Army's Steering Committee on Robotics and represents the Army at the Manufacturing Studies Board of the National Research Council. He is a participant in the executive development program (MERAD) of the Development and Readiness Command of the Army. Mr. Michel is the recipient of the Decoration for Meritorious Civilian Service of the Department of the Army. Previously, he was with Westinghouse, where he was Manufacturing Manager, Operations Manager of the Corporate Manufacturing Development Laboratory, Manager of International Projects, and Program Manager of Manufacturing at the Corporate Design and Manufacturing Center. He was a founding member of the Manufacturing Technology Committee of the Electronic Industries Association. Prior to joining Westinghouse, Mr. Michel worked for Melpar, a division of E-Systems. There he was responsible for the mechanical design of major military airborne and ground computer systems and the operation of a worldwide field service department. He was educated in Germany and the New York City school system and holds an M.S. in Mechanical Engineering from Columbia University.

The defense budget long has been a source for news and commentary. Controversy surrounds its level, its possible drain on vital social programs, and its mix—are we buying what we really need? Now an even more basic question has become the center of further controversy. Is the U.S. defense industrial base really the issue? Can U.S. industry produce the equipment that will ensure our national security in event of an emergency, regardless of what we decide that equipment is to be and what we can afford to pay for it? There is growing concern that the industrial base, particularly for defense materiel, has been ailing and that it is not getting any better.

Evidence of this malaise is seen in our declining growth in productivity, our increasing dependence on foreign sources for critical materials, manpower shortages that are projected to continue, and rapidly rising costs of weapon systems.

Concern over this issue was certainly not allayed by the results of hearings on the defense industrial base in the Housed Armed Services Committee in the Fall of 1980. In summary, major committee findings were that:

- The general condition of the defense industrial base has deteriorated and is in danger of further decline.
- Neither current nor planned DOD programs adequately address the industrial base preparedness issue.

- Shortages of critical materials and dependence on foreign sources endanger our defense capabilities.
- DOD procurement policies that sometimes discourage those types of contracts that would promote stability and encourage capital formation contribute to the problem.
- Current tax and profit policies appear to discourage capital investments that would increase productivity.
- Responsibility for the condition of the defense industrial base is widely dispersed, meaning there is little effective long-range planning for industrial responsiveness.

The diagnosis is certainly that of a sick patient. What is the prescription required to make it well?

Some cures seem explicit in the nature of the symptoms. To address the problems and shortcomings spelled out in their findings, the House committee recommended legislation aimed primarily at procurement and contract procedures, an obvious remedy. These recommendations are detailed in the committee report, "The Ailing Defense Industrial Base: Unready for Crisis", dated 31 December 1980.

Some of the recommended measures are vitally important, directly addressing specific problem areas. Of particular importance is legislation that would enable multi-year procurements. This would allow major contractors to train more skilled labor and to invest in advanced technology—measures that would increase productivity but that might be too risky without a longer term promise of return. It also would bring many smaller subcontractors (who have drifted into other industries, thus creating some of the deterioration in the industrial base) back into the defense fold. Finally, it would tend to reduce both development and production costs.

The overall problem, however, would seem to be too deep to be reached by the superficial measures recommended by the committee. The problem touches on some basic philosophies of both defense and budget planning that need to be addressed.

Before going into that, let's define the problem a little further. First, we must realize that our situation now is entirely different than it has been at times in the past—when we were caught unprepared at the start of World War II, for example. Certainly, if we could use the liberty ships, B-17's, and relatively unsophisticated ammunition of that era, there would be little problem, considering our improved manufacturing technology. We could respond faster now than we did then.

But advances in manufacturing technology are more than matched by advances in defense systems sophistication/complexity. Many of today's high technology systems are produced only thru the efforts of thousands of subcontractors. Production cycles and production management are highly complex, stretching out response times. Costs can reach astronomical proportions. Under these conditions, it would be impossible to match the mobilization effort of the early '40s. Furthermore, this high technology of today not only stretches response time; it also shortens reaction times—conflicts can break out and escalate much more rapidly. Thus, gearing our industrial base to meet whatever needs we may encounter is no small task. It is not surprising we may be falling short. Furthermore, there are two levels of requirements to be met.

First, we must be ready to meet peacetime requirements—maintain a firm defense posture and provide a surge capability for emergency situations short of war; e.g., to equip allies or a rapid deployment force or to quickly modernize some aspect of our own forces. Second, we must be ready to meet the needs of a

major conflict in whatever time is allowed. This involves what is called D-to-P computation—what quantity of war reserves must be in inventory on D-Day in order to fill the gap until the current production rate can be increased to match wartime consumption (P-Day)?

This brings us back to the basic changes in philosophy mentioned earlier. There are two points to be made. First, we need a change in our overall strategic plan, one that takes into consideration the changes initiated by the new administration. Any plan for revitalizing the industrial base must be set against some firm requirements based on a strategic overview. Definition of both peacetime and mobilization requirements, as discussed above, must evolve from this strategic plan. Priorities in the budget should also have their basis in such a plan. Much of today's feuding over items for cuts is attributable to lack of a relationship with basic strategy.

Further developing this plan, and with it a plan for industrial preparedness, is obviously a complex undertaking. It could be approached in many ways, but discussion of that aspect is not the intent here. One possible approach was outlined by Lawrence J. Korb in an article entitled "A New Look at United States Defense Industrial Preparedness" in the Third Quarter 1981 issue of Defense Management Journal. The important thing now is to recognize the need for an overall plan and initiate whatever procedures are necessary to develop one.

The second point is that, once a plan is in place, the defense budget must be built to meet it. We need to ask what is needed from the economy to meet our defense needs, not what the economy can bear, as we seem to be doing now. If the industrial base is to be stable, it must have a stable and adequate financial base. If we are to remain strong and assure our security, the economy must bear the cost. Elliott Janeway presents an eloquent argument for this approach to the defense budget in the September 7, 1981 issue of Aviation Week and Space Technology ("Defense Requirements and the National Economy", pp. 12-13).

A final point: in setting both the strategic plan and the defense budget, we need to recognize that a strong manufacturing technology program, with its beneficial effects on productivity, can play a key role in reviving our defense industrial base—a major objective. Without our past and ongoing MT efforts, the situation now would be worse than it is. We can see contributions of MT efforts in several areas.

In its report on the defense industrial base, the House Committee cited dependence on foreign sources for critical materials as one facet of the problem. There are a number of Army MM&T programs directed toward reducing use of critical materials, and results of these efforts already are beginning to alleviate this problem. Much more can be done with properly funded future efforts. The Committee report also referred to aging manufacturing equipment as a problem. Army MM&T efforts offer means to upgrade such equipment. Furthermore, MM&T efforts such as the ammunition modernization program help meet the need to provide a surging production capability in times of national emergency.

There are many more examples of specific manufacturing technology efforts that can answer some of the industrial base issues. They make a strong case for expanding the Manufacturing Technology program. Although a strong MT program by itself will not totally revitalize our sagging defense industrial base, its integration in an overall strategy would be a key factor in providing an industrial base that stands ready to meet both peacetime and mobilization requirements.

Brief Status Reports

Project 4357. ARRADCOM. Flux Leakage Inspection System for Large Caliber Munitions. No nondestructive inspection method existed with flow detection reliability established for the M483 155mm projectile. A magnetic flux leakage device purchased from the Louisiana AAP demonstrated its feasibility, but cost of operation was not determined. Contract was awarded for the design, development, and fabrication of a prototype magnetic flux leakage inspection system. Project is to evaluate the reliability and operating cost of this system compared with ultrasonic inspection systems. For additional information, contact B. Zamloot, (201) 328-2135.

Project 2446. AMMRC. Black Light TV System. Determination of feasibility of adapting a laboratory proven NDT technique to existing testing procedures for on-line production quality assurance testing. Projec was combined with Watervliet's white light inspection system project. Automatic magnetic recording borescope developed on another MTT project was accepted for use in constructing an operational black light TV inspection system. For additional information, contact R. Frailer, (617) 923-3555.

Project 2444. TACOM. Ultrasonic Testing of Roadwheels. Eighteen roadwheels for the M60 tank were ultrasonically inspected following special test equipment setup, with piggyback testing on M60A1 tanks. Preliminary signal analysis identified waveform variations and subsequently the roadwheels were inspected and delivered to the Army Proving Grounds. All roadwheels ultrasonically inspected passed the 1000 mile durability test. Testing is to continue. For additional information, contact C. Kedzior, (313) 574-5814.

Project 2426. NVL. Cryogenic Cooler Helium Leak Rate Test Set. Contractor is developing a procedure for testing common module coolers. No problems have occurred to date and design review of the test plan has been completed. One test set has been completed to determine allowable leakage, following a delay in fabrication of detail parts. For additional information, contact G. Sawyer, NVL.

Project 4041. ARRADCOM. Development of Automated Equipment for Assembly of Mortar Ammunition. The manual LAP of the 60mm XM204 and 81mm XM205 propelling charges is costly and subject to poor quality product. Development of auto equipment with the required accurate weighing and dispensing functions was the goal. Panel designs for five stations were initiated with full liaison with Milan AAP. The assembly line was fabricated and debugged. Additional funds were needed to overcome problems encountered during development. Proveout of low porosity containers was performed; the line screens out incorrectly sized containers. After debug and testing, further work was deferred to Milan AAP and Project 2007 for final acceptance testing. For additional information, contact J. Mola, (201) 328-2010.

Project 4046. ARRADCOM. Automatic Methods to Perform Quantitative Analysis of Blended Explosives Samples. Present analysis takes too long and too much powder is stored during testing. This project was intended to develop faster means of analysis and reduce storage by slashing testing time. Prioritized list of explosives to be analyzed was prepared. Effort made to develop process to analyze explosives via the polarograph technique. Present thrust is to use of polarograph with wet chemical analysis. NOL-130 primer mix procedure was successful; PA-100 explosive test analysis proved unsuccessful. For additional information, contact P. Monteleone, (201) 328-5388.

Project 4062. ARRADCOM. Automated Manufacturing Support for Mortar Increment Containers. The manufacture and assembly of the 60/81mm propelling charge increment containers is labor intensive and does not meet production requirements. This project will develop a process and equipment to reduce costs, increase production rates, and improve quality. The NC paper molding procedure was considered more adaptable to automation than the NC slurry vacuum molding procedure. Project was restructured to include M204/M205 increment containers also, using both vacuum slurry felting and paper molding methods. Both manufacturing systems are completed, with the assembly design approximately 60% complete. For additional information, contact P. Bonnett, (201) 328-5838.

Project 2455. Watervliet Arsenal. Quench Crack Detection. Difficulties were encountered in establishing automated concepts. A contract for design support was initiated to accelerate procurement of equipment. The flaw size criteria was determined and eight test specimens were obtained with natural quench cracks. The specimens were both breech and muzzle end discs that had been heat treated at Watervliet. Only eddy current detection techniques were found acceptable. The RFP ultimately called for an eddy current device. The system consists of a self-propelled inspection system capable of inspect-

ing both the 105mm and 155mm gun tube forgings. For additional information, contact V. Colangelo, (309) 794-5517.

Project 2812. ARRADCOM. Auto Procedure for the Evaluation of Charcolacoal Gas—Lives. All of the design fundamentals used in fabrication of the multiple charcoal tube tester were developed and a complete set of engineering drawings was compiled. These presently are being used in-house to fabricate and assemble the prototype. For additional information, contact L. Friedman, (309) 794-3608.

Project 2613. AVRADCOM. Inflow air Bleed Test, LTC-712 Engine. The inflow bleed test plan required a facilities audit of the test cell. An air compressor capable of causing engine stall was required and special hardware was ordered. Test results are being used for evaluation at CCAD. An RFP has been released to procure a small dedicated microprocessor system. For additional information, contact L. Procasky, (314) 263-1625.

Project 4000. ARRADCOM. Automated M55 Dt Detonator Production Equipment. The loading and packing of detonators is labor intensive and personnel exposure is extensive. The development of an automated system for production of nonelectric detonators to produce high quality units with reduced cost and increased personnel safety long has been an Army goal. A material handling/system integration-formation and review of material handling concepts was initiated and a test plan for comparing the ball and chamlee dispenser was prepared. A programmable controller was designed and assembled for a continuous pallet indexer to feed the inspection module. An automatic detonator cleaning station was fabricated and tested. Inert detonators were coated with graphite prior to testing. A cup inspection module was installed at Lone Star AAP. The final debug and test of the cup module was delayed by electronic component failure. Mate rial handling system was tested successfully. System hazard analysis was completed. For additional information, contact P. Monteleone, (201) 328-5388.

Project 2420. ARRADCOM. Calibration for Optical Scratch/dig Standards for Fire Control. Investigation of various optical instrument and visual sensing systems was conducted, breadboard systems were built in-house and tested, and a proposal was solicited from NBS. Earlier RFQ which generated only two responses was cancelled. Both proposals exceeded allotted funds. Additional funding for NBS proposal was approved and project is in progress. For additional information, contact J. Salerno, (201) 328-6430.

Project 2428. HDL. Two Channel Telemeter for 3-Inch Spin air Gun. Major subassemblies, transmitter, antenna, load programmer, etc., were integrated into a complete working system and successfully tested through the lab receiving the equipment. The telemeter projectile was successfully bench tested. During implementation, the two channel telemeter was tested on the P416 power supply and the M735 fuse. The new telemeter is designed to meet new and existing requirements necessary to test the power supplies from the production of the T361. For additional information, contact F. Allen (202) 394-2440.

Project 2025. ARRADCOM. Auto Inspection Device for Explosive Charge in Shell. The engineering model of the AIDECS machine was the basis for fabricating the test model. Mechanical failures caused delays and additional funding was necessary. The contractor provided a videotape of the machine operation and its mechanical fundamentals along with a full set of mechanical drawings. Phase III of the original contract was cancelled and four unused Cobalt-60 radioactive sources were transferred to another vendor. For additional information, contact J. Antal, (201) 328-2135.

Project 2427. AMMRC. System for Testing Slide Fasteners—Zipper System. Zippers have been tested under various loads with instrumentation modifications as procedures were developed. Results indicate that significant differences in performance of zipper systems exist among various manufacturers. Project is on schedule. For additional information, contact P. Rolston, (617) 923-3555.

Project 2433. ERADCOM. Power Supply Test Console for Second Generation Image Intensifier. A detail study of the power supply specification and testing requirements was completed, the computer system was acquired, and software was designed. The high voltage rotary switch unit selector and signal conditioning circuits were designed, programs were written, and a detailed test segment list for third generation 18mm power supplies was carried out. For additional information, contact J. Evans, (201) 544-4258.

Project 2410. AMMRC. Ultrasonic Transducer Evaluation Instrument. A prototype transducer was procured and ultimately delivered by the

vendor. The instrument is capable of generating fast beam profile measurements, both contact and immersion type transducers. Currently, this instrument is being enhanced by improving image display and computer processing capabilities. For additional information, contact J. Smith, (617) 923-3555.

Project 2431. NARADCOM. Computerized Color Matching System. Project resulted from the request of one of the bidders on the RFP. Close color matching of Army clothing long has been a perplexing problem both t to the Army and to the suppliers. The contract has been awarded and delivery of the inspection system is expected in February, 1982. For additional information, contact A. Ramsley, (617) 653-1000.

Project 2445. TACOM. Ultrasonic Tire Inspection. Eighteen hundred tires have been subjected to ultrasonic TDM inspection at four different field locations. Review of the tire history files at the four field activities found the tire failures to date to not provide statistically significant data, with most failures attributed to mechanical sources. A calibration manual for the modified TDM, which will be used at the depots until a microprocessor based tire tester becomes available, was reviewed and approved. For further information, contact R. Watts, (313) 574-5814.

Project 2403. AMMRC. Improved Standardization Weapon Chamber Pressure Measurement. A four channel signal conditioner has been constructed. This new capability is essential for the dynamic test phase when the transducer type is changed from charge, strain, or voltage for each firing. For additional information, contact S. Walton, (617) 923-3555.

Project 2419. Objective Technology and Instrumentation for Inspection of IR Components. An applications study was made and instrumentation was selected. The investigation of various optical and modulation transfer function measuring systems has been completed. For additional information, contact W. Fleming, AMMRC, (617) 923-3555.

Project 2438. High Perf Liquid Chromatographic Test of Aziridines. The necessary chemicals and equipment were acquired and the most promising analytical methods were selected. Phase I was completed, including identification and calibration of separated materials. For additional information, contact C. Huskins, AMMRC, (617) 923-3555.

Project 2418. Half Life of Tritium Luminous Lamps. Work is in progress to study the burn-in acceptance technique. The alternate acceptance technique, spectral shift with age, was outlined and necessary equipment was obtained. Fabrication, testing, and measurement of radioluminous lamps and equipment for in-house testing are in progress. For additional information, contact H. Goldman, AMMRC, (617) 923-3555.

Project 2424. Automatic Gear Tooth Contour Inspection System. Contract on this project was awarded 5 June 1981. Final report has not yet been made. For additional information, contact W. Baker, AMMRC, (617) 923-3555.

Project 2413. Testing of Tires and Elastomeric Products. A paper, "Tire Inspection, Army Needs and Requirements", was presented at an ASTM subcommittee meeting. The paper emphasized the relationship of tire failures and retreading difficulties with AR 750-36. The 4th Tire Testing Symposium Proceedings were published. Also, a monograph titled "Tire Testing Synposia, A Summary" was completed. The monograph has been published and distributed. Summarized in this document are the recommendations of the various working panels which were held as part of each of the Four Tire Testing Symposia. For additional information, contact C. Merhib, AMMRC, (617) 923-3555.

Project 2439. Specifications for Composite Propellant Binders. The agent for a derivative was selected as 3.5 dinitrobenzoyl chloride. The UV response was calibrated with derivatives of undecycled alcohol and verified with carefully prepared samples of HTPB-R45M polymer. The automatic injector was received and the liquid chromatograph was automated with the aid of a laboratory computer. A breakthrough in the workup procedure eliminated the problem of removing unreacted 3.5 DNBC and its side products. The task has been completed and the final report is available. For additional information, contact J. Carver, AMMRC, (617) 923-3555.

Project 2421 & 2414. Inspection for Threads on M223 Fuze and Electrothermal Analog Response Inspection of EED's. The contract to develop and check out the apparatus with nonexplosive devices was amended to include explosive device testing. For Phase II, the scope of work was altered to include only one loaded EED. Data handling was improved dramatically by replacing manual scanning of the digital recorder for data with cursor triggering. Thermal responses were read much faster, opening up the possibility of eventually automating the online testing. The destructive and nondestructive testing of the PA506 electronic delay detonator and the M100 electric detonator was completed. The results of the work were very encouraging; however, before the results of the effort can be fully implemented, additional testing will be required. For additional information, contact L. Meyers, ARRADCOM (201) 328-6714.

Project 2448. Improved GB Simulant. A review of the gas life data from GB testing of charcoal and gas filters was conducted and a preliminary screening of simulant chemicals was performed. Halogen substituted hydrocarbons and low molecular weight esters appear to be best suited. The preliminary simulant-GB correlation in which GB was adsorbed was mathematically modeled and candidate GB simulants were selected. These simulant candidates are ethyl propionate, isopropyl acetate, and bromobutane + 4-hydroxy-4-methyl-2-pentanone. For additional information, contact R. Morrison, ARRADCOM (301) 671-3608.

Project 2404. Auto Measurement of J-Integral Fracture Toughness. Initial test results indicated a wide range of mechanical properties for cannon components. Test had to be repeated due to failure of the existing X-Y recorder, which had to be replaced. Final results indicated that reliable and accurate measurements of J-integral fracture toughness can be obtained using the J5 method. The task was completed and a final report is available. Also, the results of the program were presented to ASTM Subcommittee E24.04 at its regular meeting, at which considerable interest in the J5 method was expressed. For additional information, contact J. Underwood, AMMRC, (617) 923-3555.

Project 2454. Improvement of Bore Erosion Gage. The centering mechanisms were modified so that the gage would produce reproducible results. Measurements were made on a 105 mm M68 tube. The measurements proved the modification to be very successful. The monitoring of thickness changes inside the bore during either the electropolishing or the chromium electrodeposition process using ultrasonic gaging (focused acoustic beam) was demonstrated. The effort was completed, with bore profiles of a 105 mm M68 tube section obtained prior to and after each electropolishing step. The thickness of the material removed correlated well with an ultrasonic pulse thickness monitor. For additional information, contact G. Capsimalis, AMMRC, (617) 923-3555.

Project 2452. Illumination of Cannon Tube Bore Surfaces for Visual Inspection. A system concept and engineering drawings were completed and delivery was taken of a prototype illuminating head using fiber optic lighting for the M3 borescope. Thus the feasibility of the concept was demonstrated. Work continued until the light loss at the junction of the borescope sections was determined. The task has been completed and a summary report is available. For additional information, contact R. Campolmi, AMMRC, (617) 923-3555.

Project P3. Low Cost System to Abate Nitrobody Pollution. An electrochemical/oxidation cell was fabricated and evaluated at the Iowa AAP. Evaluation of UV/ozonolysis for the abatement of RDX containing wastewaters was completed at the Kansas AAP. Results were coordinated with those from Iowa AAP. Final report on surfactant technology was prepared and is available. Also, TR's on the treatment of pink wastewater are available. Costs of processes were determined. For additional information, contact W. Buckley, ARRADCOM (201) 328-3572.

Project 2412. Modal Analysis of Structures. Original procurement action cancelled due to higher than anticipated costs. New contract of expanded scope was awarded for

the testing of ten honeycomb panels with various skin and honeycomb thicknesses and with controlled defects. Task was completed; it was concluded that modal analysis does not lend itself to the detection of honeycomb panel bonding flaws 2.5 inches or less in diameter. A more suitable approach would be the application of signature analysis. For additional information, contact O. Gericke, AMMRC, (617) 923-3555.

Project 2422. Inspection/Measuring Method for Spherical Surfaced Components. The technical study, engineering model, and software development scopes of work were completed. The moire technique feasibility study was completed in January 1980. RFP closing date of 29 May 1981 followed a pre-proposal question answering conference. Project is in process. For additional information, contact M. Elmowitz, ARRADCOM, (617) 923-3555.

Project 2401. Cannon Tube Automatic Magnetic Borescope Inspection. Contract let 1 Oct 79 for two MRB systems. Some difficulty acquiring a scanning motor required extension of work. Both systems delivered operational. During checkout, modifications were determined to be required. Contract was modified to include additional MRB features. These systems are being modified to inspect the 120 mm and 155 mm tubes. For additional information, contact R. Frailer, AMMRC, (617) 923-3555.

Project 2440. Gas-Liquid Chromatographic Testing of NC-Based Properties. Early instrumentation problems were surmounted to see completion of the project, except for development of a trace ingredient analysis procedure. The evaluation of column packing showed that packings in-house generally are superior to those purchased. For additional information, contact B. Alley, AMMRC, (617) 923-3555.

Project 9778. Long Life Light Emitter for Fiber Optics. Optic pigtail for light emitting diode was too brittle and had to be changed to a stronger fiber. High speed etched well leds for fiber optic communications were fabricated utilizing liquid phase epitaxy. A selective diffusion process using a fined laser emitting spot was established. Silicon nitride mask was used in soldering. Method for forming a PNP structure in a zinc diffused wafer finalized. A scanning electron microscope aided characterization of the junction. Final report available. For additional information, contact J. Paul, ERADCOM, (703) 664-1064.

Project 3010. Millimeter-Wave Sources for 60 and 94 GHz. Goal was to establish a manufacturing capability for production of impatt diodes which are uniform enough to be field replaceable in Army systems. Necessary to establish techniques and processes capable of producing silicon doluble driff impatt sources. Jointly funded with the Air Force. Contractor applied computer control epitaxial growth system and device processing. Impatt diodes made and tested for radar, target detection, and homing. Microprocessors used to optimize epitaxial growth process and automate testing. Vertical reactor used for better process control. Flow controllers added to the vapor phase reactor to improve injection doping of impatt diodes. Reduced thermal resistivity and improved lead uniformity were realized. A contract modification to add a pilot run was proposed. For additional information, contact J. Key, (201) 544-4258.

Project 3592. Improved Graphite Reinforcement—Phase III. Low impact strength of graphite fibers is due to the combination of their high modulus and average tensile strength. Objective was to develop a graphite fiber with a very high tensile strength of 750,000 psi. Induction heating more economical than plasma arc heating. Pilot scale plant designed using low cost pitch derived precursor rather than pan fiber. Several thousand feet of boron treated graphite fiber tested as reinforcement in metal matrix coupons. For additional information, contact F. Harris, MERADCOM, (703) 664-5471.

Project 8080. High Speed Fabrication of Aspheric Optical Surfaces. Project will establish tubular tool grinding and polishing techniques for aspheric two surface single element lenses. Validation will be accomplished by a spheric element retrofit into a redesigned fire control optical system. For additional information, contact S. Kopacz, ARRADCOM, (201) 328-2873.

Auto Test System Devised

Digital PCB Faults Isolated

GORDON D. LITTLE is an Electronic Engineer in the Engineering Directorate of the U. S. Army Missile Command, where he currently is Project Manager on the Department of Defense's Electronics Computer Assisted Manufacturing (ECAM) program, a recently initiated effort similar to the Air Force ICAM project. This forerunner program is being steered by an MTAG working group comprised of the Subcommittees on Electronics and CAD/CAM. The first phase of this broad based program is scheduled for 18 months of duration. Prior to this assignment, Mr. Little conducted developmental work after joining MICOM in 1971 in automated testing, microelectronics, automated test equipment, and packaging and design of a digital automatic pilot. Prior to his work at MICOM, he spent 12 years with Westinghouse, Sperry, and AMF Corp. He received his B.S. in Electrical Engineering in 1958 from Auburn University and his M.S. in Electrical Engineering in 1971 from The University of Alabama at Huntsville. He is a member of the International Society for Hybrid Microelectronics and serves as Chairman of the MTAG Working Group on Components and Packaging, a part of the Electronics Subcommittee of MTAG.

Efficient, automatic test and fault isolation of digital printed circuit boards (D/PCB's) for production and field installation presently is a vital requirement of the military and of industry. Hughes Aircraft has developed such a manufacturing technology and test system that will enable detection, identification, and location of digital faults in the advanced missile electronic systems that will be used in the 1980's.

In a ManTech program sponsored by the U.S. Army Missile Command, fault diagnosis of large printed circuit boards containing complex hybrid digital microelectric circuits was emphasized.

The Hughes enhanced, state of the art, DTS-70 automatic test system installed at Redstone Arsenal as a result of this contract provides the capability to isolate digital faults in such circuit boards to the component level with a test comprehensiveness of 90% or better.

Testing Vital

To meet current D/PCB test requirements, MICOM initiated the digital fault isolation (DFI) program with the following objectives:

- To select an optimum commercial automatic test equipment (ATE) system to test advanced D/PCBs during the 1980's.
- To establish manufacturing methods and technology (MM&T) for production test of D/PCBs having
  - Mixed or multifamily logic
  - Hybrid microelectronics
  - LSIs or microprocessors.
- To test and fault isolate to an IC pin or component.
- To procure and implement the selected ATE system with test enhancements.
- To demonstrate the ATE system's D/PCB testing and install it at MICOM.

Industry Surveyed

Preliminary steps included an industry survey for digital printed circuit board test requirements and available test system capabilities, a D/PCB testability investigation and resulting design guide, the development of digital fault isolation methodology and a comprehensive selection of the optimum ATE that recommended the DTS-70 system.

NOTE: This manufacturing technology project that was conducted by Hughes Aircraft Company was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Gordon Little, (205) 876-3604.

As implemented for the DFI program, a standard DTS-70 system was supplemented with test equipment features enabling it to test and fault isolate—to the component level—D/PCBs having mixed logic, LSI, and microprocessor devices. Figure 1 illustrates the resulting DTS-70 system configuration. Its major equipment groups are:

- 400 LPM Printer (2608 A/210)
- HP 1000/40 Computer and 20 M Byte Disc Drive (7906/020)
- UUT Bus Programmable Power Supplies, (7)
- Digital Test Unit with
  - 270 I/O Test Pins
  - Computer Guided Probe
  - Programmable Driver/Comparators
  - Repair Ticket Printer
- Keyboard/CRT Terminal.

The modular ATE system design permits economical expansion as needed for production. To increase D/PCB test throughput, programming capacity, and production management reports, one HP 1000/40 computer can operate three test stations with operator terminals and three additional terminals on a time sharing basis.

The equipment selected to enhance D/PCB automatic testing and to extend fault diagnostic capability from the circuit node level to the component level includes:

- Signature Analyzer (SA)—bus controlled through Hughes-originated FORTRAN software for LSI and microprocessor tests.
- HP-IB-(IEE-488)—bus control for the data transfer of the SA unit or of 14 additional bus controlled instruments.
- HP Digital Probes/Gen Rad Fault Probe—to isolate a note fault to the component level.
- Seven UUT Power Supplies—bus programmable for wide voltage and current range PCB requirements.

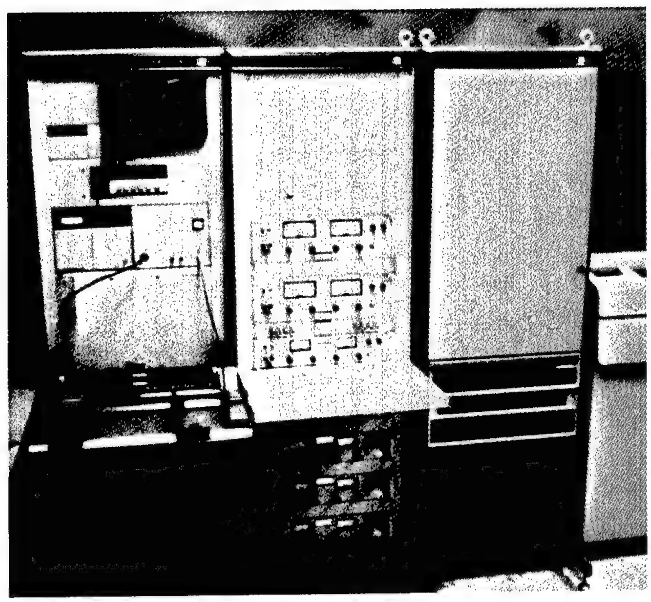


Figure 1

Worst Case Boards Chosen

A D/PCB survey was conducted to find the most complex D/PCBs available in today's industry. From the resulting list of 21 D/PCBs (representing the worst cases any ATE system would have to test) the 1635972 and the 1646178 D/PCBs were chosen as the final test candidates to be used in the ATE Implementation phase of the DFI project.

The 1635972 D/PCB is a microprocessor board used in the Signal Processor of the AN/TPQ-36 Firefinder Radar. It's complexity is due to the LSI devices found on the board and not necessarily to the number of IC's—of which there are only 28. The 1635972 board contains the following LSI devices:

- Intel 8080-microprocessor
- 8228-system controller data bus driver
- 8255-programmable peripheral interface.

These devices in conjunction with the bidirectional bus capabilities of the board make the 1635972 D/PCB an excellent test candidate for the project. A photograph of the 1635972 board is shown in Figure 2.

The 1646178 D/PCB is the HMD-22 display microprocessor used for air defense and air traffic control. The board's large size and complicated logic make it a prime test candidate for the DFI project.

The 1646178 board is difficult to test because it contains:

- **LSI devices**—Four AM2901 microprocessors. The AM2901 is a four-bit microprocessor slice which is cascadable to any word length. With four AM2901s mounted on the card, the 1646178 board becomes a 16-bit microprocessor.

- **Sequential Logic**—Having 142 IC devices mounted on it, the board has the fault visibility problems associated with sequential logic.

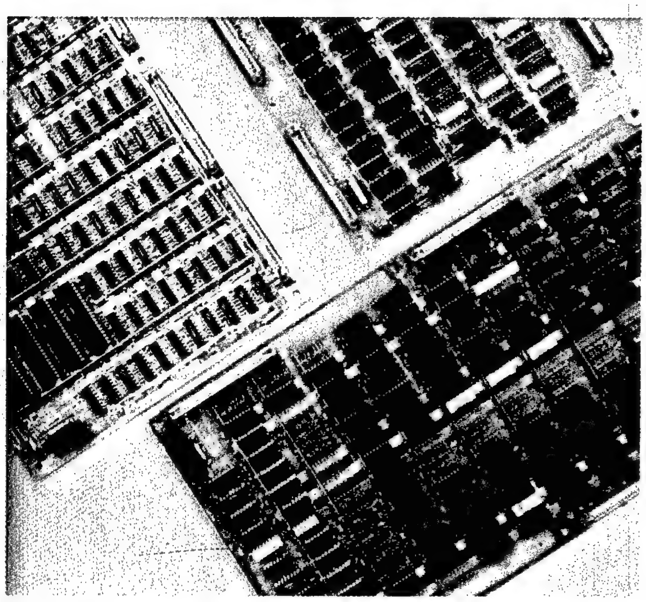


Figure 2

The 1646178 D/PCB was chosen as the second test candidate because its LSIs and sequential logic made it a complex board to test. A photograph of the board, with the 1646178 board mounting test hardware still attached, is shown in Figure 3.

Innovative Software Required

Signature analysis, LSI modeling, and FORTRAN software were developed in combination with conventional digital techniques to test the -972 PCB. The -178 PCB requires AM2901 functional models in combination with conventional digital techniques.

Five elements of system executive software combined with Hughes originated FORTRAN test or application software achieve effective D/PCB testing, data base management (DBM) of production records and reports, ATE system maintenance reports, and system diagnostic or performance self testing. The system software element features and their use or application are summarized in Table 1.

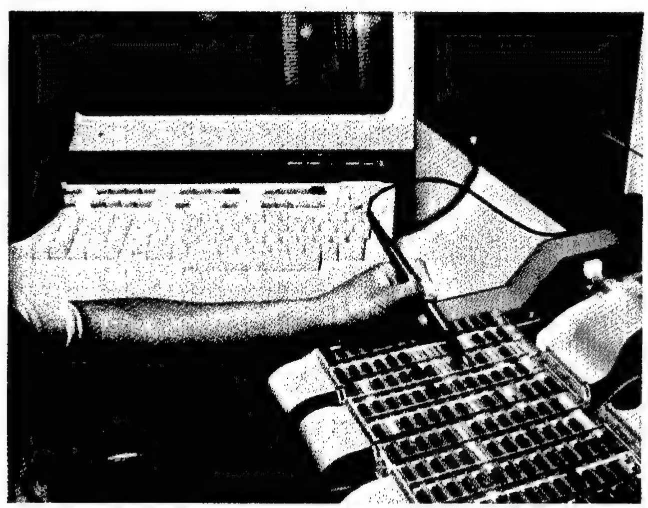


Figure 3

RTE IVB—The Real Time Executive (RTE) version IVB is the operating system software. It programs in FORTRAN and HP Assembler with expansion capability for other languages. RTE manages operations of the computer, main memory, disc memory storage, and all I/O devices.

DTS-70 Executive and DFI Application Software					
Software Type	Identifier	System Disc Residency Fixed (F) Movable (M)	Principal Language	Interface Language	End Use
System					
Real Time Executive	RTE IVB 92067 A/031	(F) LU 2,3	HP 1000 Assembly	FORTRAN	Controls all system operations
TESTAID/FASTRACE III	91075 B, IVB	(F) LU 2,3	HP 1000 Assembly	NONE	PCB test simulation and fault isolation
IMAGE 1000/(IVB)	92063 A/020	(F) LU 2,3	HP 1000 Assembly	FORTRAN	Data Base Management
Functional/Test		(F) LU 2,3	HP 1000 Assembly	NONE	System Functional Test
Application					
Signature Analysis	SACMPR	(M) LU 18	FORTRAN	—	—972 PCB Test, 8080 A/B
µ Processor Initialization	INIT/NOOP	(M) LU 18	FORTRAN	NONE	—972 PCB Test, 8080 A/B
Line Deleter—Make Undetectable	LNDEL/ MKUND (SPEDUP)	(M) LU 18	FORTRAN	NONE	Produces TEST-AID simulator source file to remove previously detected faults
Fault Isolation —972 PCB	FIF 972	(M) LU 18	HP 1000 Assembly	NONE	—972 PCB Test Post Processor Files
Fault Isolation —178 PCB	RHFAIN RHFFLG RHFABO RHFBIN	(M) LU 15 (M) LU 15 (M) LU 15 (M) LU 20	HP 1000 Assembly HP 1000 Assembly HP 1000 Assembly HP 1000 Assembly	NONE	—178 PCB Test Post Processor
Support Facilities	DFISML, SMRPT	(F) LU 19	HP-Image, Query	FORTRAN	DFI System Support Maintenance Log and Report

Table 1

IMAGE/1000—This is a user oriented data base management system that is interactive with BASIC, FORTRAN, and HP Assembler. It can be operated from multi-terminals and has provisions for protecting the data base from unauthorized users. IMAGE may be used for production inventory control or production test reports.

TESTAID—This software supplies simulator based test program generation for D/PCB's. It can be used to both manually and automatically generate test patterns for fault isolation, while simultaneously keeping track of the percent fault detection. TESTAID is made up of the following subprograms:

- SGLST—Topology generation
- SMSET—Fault directory generation
- SIMUL—Simulator and test pattern generation
- PATDK—Post processor program, creates the Preliminary Test File for FASTRACE.

Basically, TESTAID generates the test program and FASTRACE executes the test program generated by TESTAID.

FASTRACE—This software provides test program execution for D/PCBs. It performs pass/fail testing and the computer guided probing if a failure is found. FASTRACE is made up of the following subprograms:

- SETUP—adds hardware setup data to the Test File.
- CHECK—performs hardware confirmation of values specified in SETUP.
- PONOF—applies and removes power from the UUT.
- GONO—performs the pass/fail test on the UUT.
- PROB—performs fault isolation to the node on a failed UUT.

Diagnostic Self Test—Software for two tests is provided to verify test station operation. These are the System Functional Test (SFT) and the System Performance Test (SPT). The SFT is a comprehensive test which verifies that the various stimulus, response, measurement, and switching functions of the Digital Test Unit (DTU) are working correctly. It serves as a good test for checking system integrity before actual production testing begins. The SPT serves as an excellent overall system calibration test and is used for maintaining functions to the required specifications.

Signature Analysis Saves Time, Money

Modeling microprocessors is a time consuming process, and in some cases is not feasible. Signature Analysis (SA), to be used with the DTS-70, provides a cost effective and work saving alternative approach in testing microprocessors on a D/PCB.

To use the HP 5004A Signature Analyzer with the DTS-70, software programs called No Operation (NOOP), Initialization (INIT) and Signature Analysis Comparator (SACMPR) were developed by Hughes for testing the 8080 A/B microprocessor on the -972 D/PCB.

SACMPR directs the operator to manually probe IC pins as directed by the computer. SACMPR is a FORTRAN software package which enables automatic comparison of

stored signatures in the data table of the computer's disc memory with unknown UUT signatures probed through the signature probe and passed through the HP-IB bus. SACMPR software was developed so that it can be used universally for the Signature Analysis testing of D/PCBs once the correct reference signatures for the D/PCBs have been entered into the program's data table.

The advantages of using Signature Analysis for testing microprocessor based boards include the following:

- The microprocessor does not have to be modeled, which reduces test program development time considerably.
- Simulation time is reduced since the D/PCB is tested without the microprocessor using TESTAID.
- Similar microprocessors can be tested by using the SACMPR program.

The disadvantages of Signature Analysis testing include the following:

- It requires a known good board to acquire reference signatures
- It requires a program to free run the microprocessor.

Since the basic SACMPR software has already been developed by Hughes, the development of a Signature Analysis procedure for other microprocessor based boards would require anywhere from one to three man-weeks. The digital test station block diagram is shown in Figure 4.

As shown in the figure, the following test enhancements were added to the system to increase its testing capabilities:

Signature Analyzer—The signature analyzer (SA) is a data compression device that takes data from an IC node and serially feeds it into a 16 bit feedback register. It then takes the contents of the register and encodes them into a hexadecimal signature. The data are sampled during a specific time interval so that the "good" signatures taken are repeatable. The SA unit detects 99.998% of erroneous data and 100% if the error involves a single bit or a mid cycle misplaced bit.

For microprocessor or LSI testing, the measured UUT pin signatures of a known good device are located in a

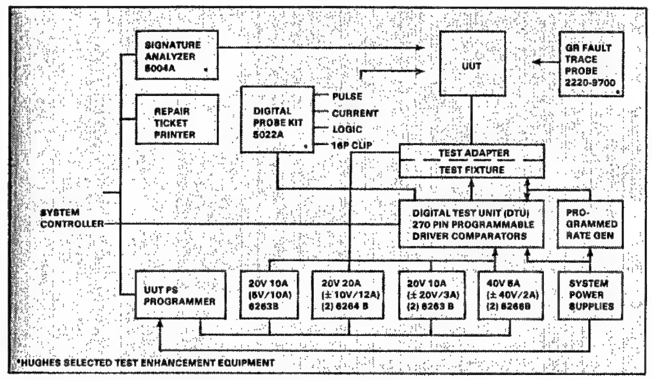


Figure 4

system file and serve as a test standard for other ICs of the same type.

Digital Probe Kit—The HP 5022A Digital Probe Kit contains 4 trouble shooting aids for fault isolation to the component level. The kit contains the HP 547A Digital Current Tracer, the HP 545A Logic Probe, and the HP 548A 16 Pin Logic Clip.

GenRad Fault Probe—The GenRad 2220 Fault Probe is an instrument used to resolve a board node fault and locate the faulty component. It can be used to find faulty ICs, shorts and open circuits. The GenRad Probe has 3 modes of operation: the Signal Trace mode, the Connectivity mode, and the Microvoltmeter mode.

The Signal Trace mode works by injecting a 600 kHz trace current between the 2 shorted nodes and following the etch with the current-tracing probe to the fault location.

In the Connectivity mode two probes are used, one placed on a known node, while the other is swept across the board until the unidentified faulty node is found. This mode is also used to locate open circuits.

The Microvoltmeter Mode requires that the two shorted nodes be identified. A 10mA DC current source is then connected between nodes to provide a potential gradient along the etch carrying current. The small IR drop is sensed by the microvoltmeter as an increasing or decreasing potential as one probe is moved away from the other along the track. When the meter reading no longer changes the short has been found.

By inserting a known good board into the Test Adapter and probing signatures at preselected nodes, a good board

data table is created (see Table 2) which contains a listing of the nodes to be tested, identifies the correct signatures for each node, and provides testing instructions to the operator.

SPEDUP Important

Because of the large quantity of test patterns (over 2500) required to test the 1646178 D/PCB, a Hughes developed software package, SPEDUP, was used to reduce the TESTAID simulation time. SPEDUP can be used to reduce testing time for other D/PCBs as well. The use of SPEDUP eliminates repeated detection of identical faults as new test simulations are run, and thus saves both computer run time and disc storage.

DFI 90-98% Comprehensive

Testing of the -972 PCB is achieved by test software comprised of two major parts. First TESTAID/FASTRACE is used to test the entire PCB with the 8080 A/B removed from its socket and replaced by a 40 pin umbilical test line supplied with digital test patterns through the DTS-70. Second the 8080 A/B microprocessor is placed in its socket and is allowed to free run through an adapter ROM. SACMPR, the Hughes originated FORTRAN program using Signature Analysis, then compares 8080 A/B UUT pin signatures with known good signatures stored in file.

Sample Signature File for 8080 Microprocessor															
	Node Name						Correct Signature				Good Flag	Bad Flag	Good GoTo	Bad GoTo	From
Row	1		2		3		4		5		6	7	8	9	10
#	1	2	3	4	5	6	7	8	9	10	11 12	13 14	15 16	17 18	19 20
1	U	4	5	·	2	0	7	5	5	U			2	0	0
2		U	4	5	·	2	0	0	0	0			3	0	0
3		U	4	5	·	1	H	H	8	6			4	0	0
·			·										·	·	·
·			·										·	·	·
·			·										·	·	·
28	S	T	O	P	S	T									
29	E	N	D	E	N	D									

Table 2

In either part of the test, the test terminates on a failed step, and either FASTRACE or the SACMPR directs the operator probe to the faulty node.

The 175 test patterns used were manually generated and provide an overall test comprehensiveness of 98 percent. The automatic test pattern generation feature in the DTS-70 TESTAID was not used because of a 10 fold, or one order of magnitude, increase in test patterns and a consequent increase in simulation time.

The software for the -178 PCB consists of four major parts utilizing 2568 test patterns for an overall test comprehensiveness of 90 percent. TESTAID/FASTRACE is used for the entire test and includes logic models for LSI and AM2901 devices. Specific operating requirements of the system automatic pattern generator were not workable with the PCB sequential logic operation and therefore manual test patterns were generated.

Test software for the -972 and -178 PCBs proved highly effective during the test demonstrations as determined by the tabulated test results.

Test Runs of 0.2 Minutes

The time required for testing the 972 board without the microprocessor is 0.3 minutes, and 8080 microprocessor test itself takes 8.0 minutes. The total time required for the -972 board GO/NO-GO test is 8.3 minutes. However, the GO/NO-GO time for the 8080 microprocessor test can be improved by using multiplexing techniques rather than manual probing of its 40 pins.

Fault isolation performance data shows the length of time needed to isolate the different faults. Three different types of faults, stuck at zero (SA0), stuck at one (SA1) and Solder Bridge (SB), are inserted manually at the indicated IC pins and the fault isolation time measured. The time required to isolate SA0 faults is between 0.2 minutes and 5.9 minutes. For SA1 faults, isolation time is between 0.2 minute and 3.1 minutes, and for SBs it is between 0.4 minute and 3.6 minutes. A summary of test results is shown in Table 3.

System Reliable

The only items requiring maintenance on the system in over 2500 hours of operation were a 94151A Program-

DTS-70 Test and Fault Isolation Performance for Microprocessor D/PCBS					
D/PCB Test Candidates	Number of ICA	GO/NO-GO Test (Minutes)	Fault Isolation Mean Time (Minutes)		
			SA0	SA1	SB
1635972 (8080 A/B)	28	8.3*	1.2	1.7	1.1
1646178 (AM2901)	142	1.5	5.9	2.0	3.2
*USCS manual probing of 40 pins on the 8080 A/B.					

Table 3

mable Driver/Comparator Card and a TESTAID Fault Isolation Probe. Both items were serviced so that system operation was interrupted no more than 2.5 hours.

The programming times for the various tests are listed in Tables 4-6. D/PCB design changes devoted to testability could save many hours at the testing stage.

One of the most difficult tasks for the test engineer is the initialization of the D/PCB. In many cases the initialization can be accomplished with a few extra test patterns added to the beginning of the test sequence to bring the board to a known state. But in some cases, the D/PCB can never be initialized using conventional software techniques, and requires special hardware modifications to be initialized. This time and effort could be completely eliminated if more attention were focused on the D/PCB's initialization at the design development stage.

Another recommendation for the design of digital PCBs is the use of sockets with all microprocessors and ROMs. The use of sockets for microprocessors and ROMS would widen the scope of possible test strategies for any PCB and therefore improve the PCBs' overall testability.

1646178 D/PCB Programming Summary, Hours							
Items	Design	Topology Editing	SGLST	SMSET	SIMUL	Hardware Verification	Total
AM2901	80	120	8	4	40	24	276
ROMS	8	16	8	4	8	8	52
Complete 1646178 PCB	0	80	40	8	600	80	808
Total	88	216	56	16	648	112	1136
Gross Time = 28.4 weeks (with learn factor)							

Table 4

Feedback loops are another source of problems for the test engineer. When such loops exist it is difficult to locate a fault's origin within the feedback loop. If special logic were added to externally break these loops, a fault could be isolated down to a single node without the use of additional equipment (i.e., GR 2220 Fault probe.)

The final recommendation involves putting pullup resistors on all tristate nodes because a logic probe cannot sense a passive node. The output of a disabled tristate element is a passive logic '1', which means the output floats to a value that the board hardware will interpret as a logic '1'. Because such a node is passive, it cannot force a logic probe to a valid logic state and is flagged as a faulty node when it is tested. In the case of the DTS-70, tristate elements could not be handled without the addition of pullup resistors unless special modifications were made to the tristate models from the HP library.

Another problem is exemplified by errors found on the 1646178 board schematic. These schematic errors had to be corrected in the software topology so that the physical hardware and the software model of the 1646178 D/PCB would match. At first glance, this type of problem would seem easily corrected. But, since any changes to the software topology require over 350 hours to resimulate the complete test, the problem of topology errors on the 1646178 board is not trivial.

Improved testing procedures such as the system outlined here—combined with design devoted to testability—will promote new standards of quality and cost savings in the industry.

Manpower Distribution for TESTAID/FASTRACE Test Program, Hours							
Items	Design	Topology Editing	SGLIST	SMSET	Simul	Hdwr/Sfwr Verification	Total
LSIS, ROMs, RAMs	200	88	56	40	200	200	784
1635972 Board	0	40	80	40	120	280	560
Total	200	128	136	80	320	480	1344

Table 5

Manpower Distribution for Signature Analysis Test Program						
Items	Concept	Algorithm	Coding	Edit	Debug	Total
FORTRAN	48	148	88	64	88	436
Adapter ROM	16	16	8	8	16	64
Total	64	164	96	72	104	500

Table 6

Automated Flexicon Facility

Flexible PC's With Integral Molded Connectors

By Gordon D. Little, Project Engineer
U. S. Army Missile Command
(Mr. Little was author of the preceding article; his biographical sketch may be be found on Page 11.)

Specific design requirements for automated part handling and positioning to accomplish reliable, low cost FPW termination and encapsulation were the goal of a manufacturing methods and technology project with the U.S. Army Missile Command by Westinghouse Electric Corporation.

This automated process is designed to handle planar two row connectors on .050 inch centers at a production rate of 500 connector assemblies per 8 hour shift. It features the application of industrial laser techniques to the requirements of FPW stripping and to the welding of the copper foil circuit leads to the connector pins. Also, the utilization of fast cure liquid resin injection molding (LIM) permits inclusion of connector to flex circuit encapsulation as part of the in-line process. (Initial use of this technology was presented in the preceding article.)

Human Intervention Minimized

The automation of any fabrication process must be able to control that process within all tolerance extremes to ensure consistently good output. Also, this automation must minimize human intervention to increase the process reliability. If an operation must be performed under human control, it is affected by all the possible variables of the human. If it can be reliably controlled by a machine, then the machine variables affect the output. In simple machines, those variables may only be tool wear or loss of power. Thus the second most important reason for full automation is **consistency** of output. The first most important reason is **cost savings.**

Capital Costs/Recurring Costs

In considering the cost effectiveness of the automated facility, the basic costs have been broken into two groups—capital and recurring. Capital costs include basic equipment and maintenance. Recurring costs include material and labor for the product being produced. Detailed analysis shows that capital expenses (estimated at around $300,000) will be about equal to those required for competitive processes at the same production rates. Recurring costs, cost of goods and services, are one sixth those encountered with existing alternatives.

With the combination of consistency of product (reliability) and significantly lower cost, the philosophy of systems maintenance dramatically changes. Instead of

NOTE: This manufacturing technology project that was conducted by Westinghouse Electric Corporation was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Gordon Little, (205) 876-3604.

repair of assembled units which might be damaged, replacement is the lowest life cycle cost alternative. Other secondary benefits add to the improved life cycle cost by increasing aircraft mission effectiveness because of an increased use of flexible printed wiring (FPW) and flat conductor cable (FCC) brought about by lower basic cost. These reduce required volume for interconnection and reduced interconnection weight by as much as 70 percent.

To provide for an optimum usefulness of this approach to many systems and connectors, the maximum control of the processes through programmable software has been made. This minimizes hard tooling requirements to a few pieces, and establishes full control of all of the processes within the flexibility of the processor.

Processes and automation have been developed to meet a capability of fabrication of up to 500 assemblies per eight hour shift.

Flexicon Process Flow Automated

The automated Flexicon process has three basic steps; laser stripping of the flexible printed wiring (FPW), laser welding termination of FPW leads to connector, and assembly encapsulation. The straight-line flow is charted in Figure 1. Under controlled conditions, a pulsed CO2 laser is used to ablate the insulating material surrounding the copper leads in the area which is subsequently to be terminated to the connector. The focused light energy of 10.6 micron wavelength discriminates between the copper, which is highly reflective to this wavelength, and the plastic covering layers and the adhesive layers which readily absorb the energy. At the energy density levels used, this causes virtually instantaneous heating of the organic materials to vaporization temperature while leaving the copper undisturbed. A simple cleaning process involving bristle brush stroking and solvent wash of the exposed copper dislodges any particulate char which may remain.

A Neodymium:YAG pulsed laser is used to weld the copper leads to the contact tails of the connector. The focused light energy of 1.06 micron wavelength is readily absorbed, in this case, by the copper leads. Absorption of the focused light energy rapidly raises the temperature of the metals to cause a fusion weld to be formed.

Automated electrical test is performed on each weld termination to verify acceptable conductivity. Automatic visual inspection is an optional feature which may be implemented by several methods, for instance, use of the specular signature of an acceptable weld nugget as criterion in an electro-optical system.

Encapsulation which provides the necessary electrical isolation between adjacent leads and strain relief transition from connector to unsupported flex circuitry is the last process step. A quick cure liquid resin system is utilized which makes it possible to automatically load the mold and encapsulate the Flexicon assemblies in line with the preceding process steps. This avoids any manual handling of the relatively fragile assemblies before molding.

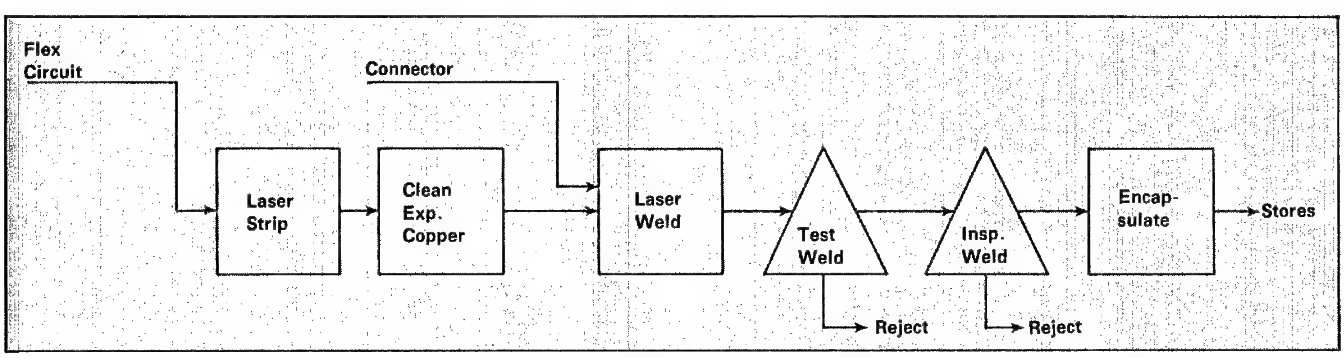


Figure 1

Control Programmable

The primary feature of the Flexicon Automated System is the application of programmable control to all aspects of the system to minimize the need for hardware type tooling dedicated to a specific Flexicon assembly. By utilizing programmable control, many aspects of machine and process parameters are removed from hardware definition and are brought under software definition. The benefit of software control is that while absolute fidelity to the program is maintained during the machine cycle, an infinite number of programs can be generated and rapidly changed to deal with assembly style changes or process variables. Accordingly, the geometric character of the connector and flexible circuit (i.e., pitch and number of connector leads to be welded) are controlled by software and are easily changed or modified by software with only minor hardware modifications required.

In addition, the complexity of the automation type tooling required for this system has been greatly simplified by the microprocessor control. The precision motions required or guiding the flex circuit and assembly through stripping, welding, test/inspection, and mold loading are derived from the capability of the microprocessor to control the position of an x-y table and not from mechanical mechanisms intrinsic to the hardware itself.

The application of programmable control to the Flexicon system falls into three categories: control of processes (laser welding, laser stripping, and encapsulation), control of position (index entrained connectors, translate flex circuit past CO_2 laser beam, translate assembly past Nd: YAG laser beam, and load welded assembly into encapsulation mold), and control of system timing (coordinate system events in series and parallel.)

Process Control Desirable

Control of critical processes is the most desirable application of programmable control since precise, repeatable control of critical operations is achieved. In this system, for instance, software is utilized to precisely coordinate the laser spot welding with the position of the target. This is done by electronically counting position command pulses to the positioning table, which is translating the flexible printed wiring/connector assembly in the laser focal plane, and timing the laser firing command to the position count which corresponds to a flex lead connector in proper weld position. With this type control the welding of connector to the leads can be done quite rapidly; in fact, it is limited only by the time required to recharge the laser firing circuit between pulses.

In addition, a characteristic of a pulsed welding laser is the necessity to start the firing pulses in advance of the first weld in order to thermally stabilize the lasing system and establish uniform energy density at the target. One way to achieve this is to start the train of laser pulses in advance of the first target and dissipate the energy into the system's closed shutter. The shutter is then timed to open just before the first weld target is in position. Similarly, the laser stripping process is controlled by software; cover gas, vacuum, laser pulsing, and laser shutter control are also rigidly controlled by the software program. The injection molding process parameters (e.g., time and temperature) are precisely controlled by the program. They can be changed to new parameters by a change in the program.

Programmed control of position is accomplished by mounting some parts of the system hardware on two compounded, servo controlled, machine type linear slides. In-process Flexicon assemblies can thereby be moved in a horizontal plane relative to the fixed positions of the two lasers and the molding press.

Position Control of 7 Assemblies

In the second category, programmed control of position is accomplished by mounting the parts of the system hardware which support the assemblies on two compounded, servo controlled, machine type linear slides. In-process assemblies can thereby be moved in a horizontal plane relative to the fixed positions of the two lasers, the molding press and the FPW and connector inputs. The FPW is translated in the focal plane of the CO_2 stripping laser and also the Neodymium:YAG welding laser by software control of the positioning tables with no other mechanical assist required.

At any time in the operation of the system, there are up to seven assemblies in process. By means described below the assembly can be indexed readily from one process station to the next by a programmed table motion controlled by the software. The flexible circuit is input to the process and translated in the focal plane of the CO_2 stripping laser and also the spot welding Neodymium:YAG laser by software control of the positioning tables.

System Timing

System timing is the third category where programmable control is applied. Event timing is an essential element in this automated system. In the section of kinematics in this report, it is shown how the many process events and motion routines are orchestrated by the software program. Extensive use has been made of programmed cues ported to external control hardware to initiate program subroutines such as manipulation of the flex from input through laser stripping and subsequent transfer to the laser welding operation. A secondary feature of the automated system design is the integration of all three primary processes steps, strip, weld, and encapsulate into one functional unit. Mechanical tolerances on the relative positions of the various elements are mechanically linked together by a common base of granite. The dimensional precision and inertial stability required for the laser processes are thereby assured.

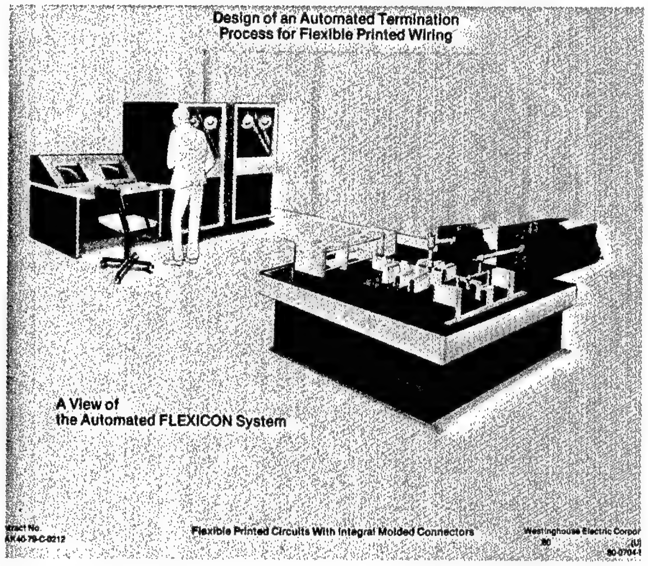


Figure 2

In-Line Processing

The components of the systems are arranged to provide in-line processing through all steps that end with a finished, tested Flexicon assembly. A perspective view of the Flexicon Automated System is presented in Figure 2. The automated Flexicon system has, as its central feature, tooling mounted on a computer numerical controlled (CNC) linear slide table which provides x-y motion in the horizontal plane. Programmable control of the position of the tooling relative to the fixed positions of the two lasers and the mold press allow system design to be simplified.

As depicted in Figure 3 the x-y positioning slides are mounted centrally on the granite surface plate.

Referring to Figure 3, the steps are:

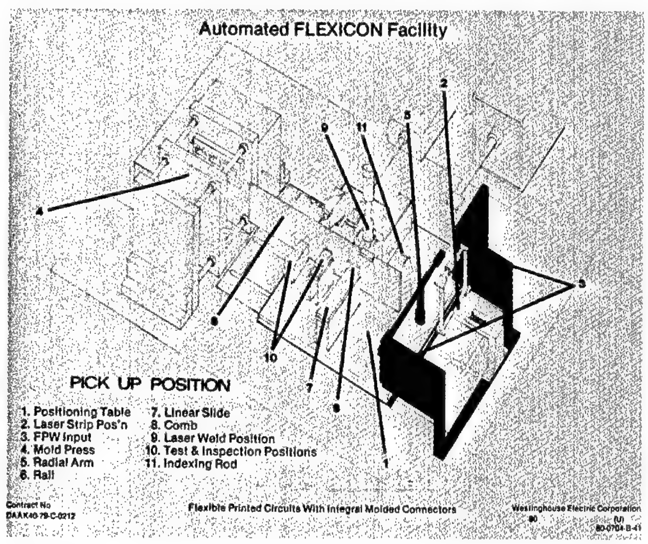


Figure 3

1. Tooling to support and reference the connector and flex assembly through the welding, test and inspection process is mounted on the positioning tables.

2. The facility of CO_2 laser stripping and cleaning is positioned in the righthand foreground of the surface plate. Note that this laser, as well as the Nd:YAG laser for welding, is referenced to the granite base. (Localized laser energy shielding is not shown, for clarity of illustration.)

3. Containers for presenting stacked, pre-oriented FPW to the system are located on each side of the stripping facility.

4. The molding press is located at the opposite end of the granite base. It is oriented horizontally.

5. The radial arm structure, mounted on the positioning table in the foreground, has two functions. The radial arms can be rotated in the horizontal plane. The longer arm is equipped with a vacuum platen which is used to acquire a flex circuit from the preoriented stacks and manipulate the flex through the laser stripping and cleaning process. The shorter arm is used to acquire a connector from the connector input station and transfer it to the vertical rail.

6. The prominent tooling feature on the positioning table is the rail structure, which supports the assembly in a vertical orientation with the pin rows straddling the top edge of the rail. The rail permits symmetrical access to each side of the connector pin rows and provides vertical clearance for the trailing flex.

7. On the table are two linear slides, positioned on each side of the rail.

8. Each slide supports a vertical vacuum platen with a comb-like feature at the upper edge. The comb tines interdigitate with the stripped flex conductors to provide mechanical registration of the flex with the system. The slides can be rotated in the horizontal plane to align the slide's vector alternately between the radial arm for flex transfer to the slide and the weld position at the rail.

9. Welding takes place as the connector and registered flex are transported in the focal plane of the horizontally oriented Nd:YAG laser beam. Welding is done sequentially, first on one side of the connector and then on the second side.

10. Electrical test and visual inspection stations are also located on the positioning table downstream from the weld station. This permits concurrent test and inspection of previously welded assemblies.

The overhang of the rail beyond the positioning tables provides space queueing acceptable assemblies and then moving the table to position the assemblies in between the mold halves.

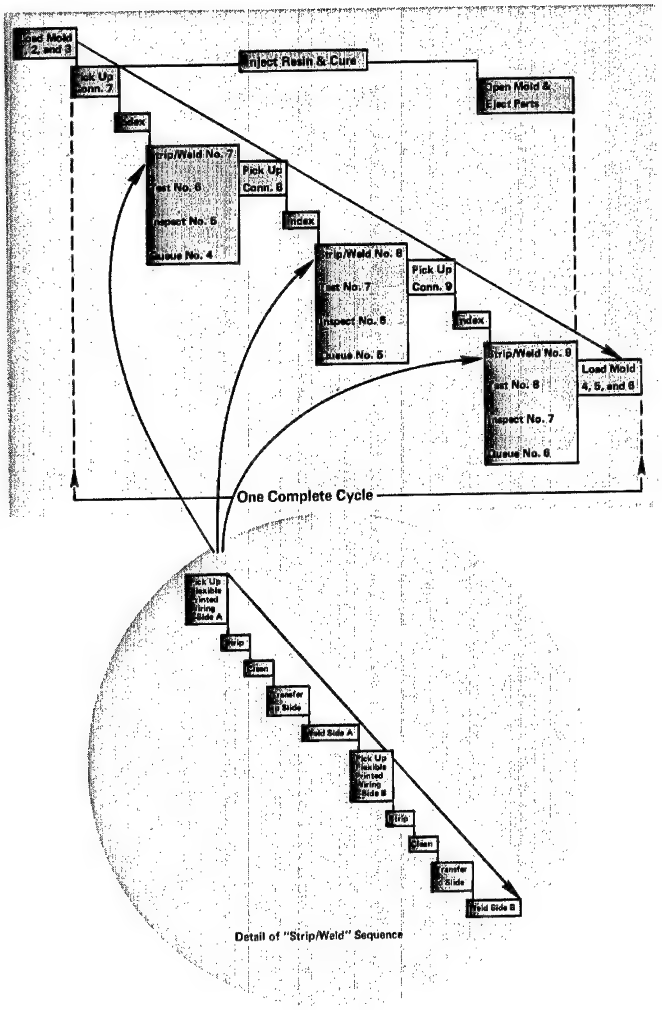


Figure 4

Event Sequence Summarized

Figure 4 shows the overall sequence of events. First, the system cycle spans the time required to produce three assemblies. Because the encapsulation curing cycle requires a longer time than the other assembly cycle times, it is necessary to queue the welded assemblies until three at one time can be inserted into the matching three cavity mold. Also, the electrical test and electro-optical inspection take place concurrently with the flex stripping and welding. This is made possible by having the hardware for these functions mounted on the positioning tables.

The first event in the automatic process occurs when the vacuum pickup platen on the radial arm is brought into contact with the preoriented stack of FPW in the foreground. The table backs away from the stack with the circuit held to the radial arm by pressure differential. This event is that illustrated in Figure 3. The radial arm then rotates counterclockwise 90 degrees in the horizontal plane and commences a series of back and forth passes in the CO_2 laser beam; at the same time it is incremented vertically with each pass. This causes the cover coat to be ablated exposing the copper circuits. The stripped circuit is then mechanically cleaned and washed by advancing the circuit into the brushes positioned in line with the laser focal plane.

The radial arm then rotates counterclockwise an additional 90 degrees. At this point the slide mounted comb is caused to rotate 90 degrees clockwise in the horizontal plane and advance the comb to engage the FPW. Control of the FPW is transferred to the comb by inhibiting vacuum on the stripping platen and enabling vacuum on the face of the comb. The slide then retracts with the flex attached, rotates 90 degrees clockwise to return to its start position. Again the slide advances and engages the previously positioned connector, aligning and clamping the circuit leads to the connector pins. The table then moves the assembly into the focal plane of the Nd:YAG laser and commences the spot welding routine. At the completion of the weld cycle the vacuum is inhibited and the slide retracted to start position. This sequence is repeated again, in mirror image, for the second side of the connector.

During the period when stripping and welding are taking place, previously welded assemblies are being tested and inspected automatically. The slide mounted probes are caused to advance and contact in the weld area to electronically verify continuity and acceptable conductivity of the weld joint. Cameras for the optional optical inspection are positioned next in line on the table.

Indexing Cycle Initiated

At this point in the process the table moves to bring the shorter radial arm in line with the connector input station positioned next to the CO_2 laser housing. Through an escapement mechanism, one connector is pushed onto the arm. The arm rotates 90 degrees counterclockwise to align with the rail.

With the new connector in this position the indexing cycle starts. The entrained connectors are each simultaneously moved to the next station on the supporting rail. This includes moving the connector on the arm to the first position on the rail. Indexing is accomplished by the rod with radial spokes supported by the Nd:YAG laser column. This rod is rotated 180 degrees about its major axis which brings the radial spokes into position between the connectors. The table is then caused to move from left to right, whereupon the connectors, initially moving with the rail, each encounter a spoke on the rod. The spoke acts as a stop to the connectors, holding each stationary while the rail continues to move until the next station on the rail is precisely registered with each assembly. The rod is then rotated back to its start position. This next step depends on the status of the assembly queue waiting for transfer to the molding press at the far end of the rail. If the queue is not full, that is, there are not yet three assemblies in the queue, then the sequence beginning with flex stripping will occur again. If, however, the queue is full, then the contents of the queue will be transferred to the mold cavities. In this event the table moves from right to left to bring the assemblies in the mold queue into the space between the mold halves. The mold then closes partially, nesting the connector bodies in the mold cavities. The rail is then withdrawn, leaving the assemblies in the mold. The mold then closes completely and the molding cycle commences. The molding cycle ends when the mold is opened and Flexicon assemblies are ejected from the cavities. The assemblies fall between the mold halves to a tray located below.

Microprocessor Calls Shots

As previously stated, the Flexicon System is designed for programmable automation in which hardware tooling is minimized and the advantages of control by software are fully exploited. A microprocessor based CNC system is used for the following functions:

- Positioning commands for the two axis positioning table
- Firing commands for each laser, coordinated with the position of FPW or assembly
- Control of all other system events through external porting of program commands to interfacing hardware, such as olenoid valves.

All system events which are of a routine nature (not subject to change when a style change occurs) are controlled by programmed subroutines. They are cued through external ports of the microprocessor control. Some of the subroutines which are sequential in character are: indexing, connector pick up and transfer to rail, FPW pickup and radial arm motion, FPW transfer from radial arm to slide, FPW cleaning cycle, mold closure cycle, load mold cycle, injection cycle, laser cover gas control, Nd: YAG laser beam steering, continuity test sequence, and inspection sequence (optional).

Design Requirements

To support and interrelate process hardware, a granite surface plate was used. It has sufficient strength and dimensional stability to support the hardware and maintain alignment of laser optics with the positioning table tooling. It also has sufficient mass to dampen reaction to positioning table movement.

The requirement to selectively ablate the FPW insulation cover while leaving the copper circuit undisturbed dictated the use of a CO_2 laser. Equipment with an average power output range of 150 watts is required. A pulse repetition rate of 500 Hz controllable by external command is also required.

The stripping process is performed by making successive passes with the flexible printed circuitry between the focused beams. The motion of the material must allow for sufficient overlap of the spot patterns to ensure complete removal of insulation. FPW transported in a path parallel to the .0083 inch width of the beam spot should receive a beam pulse every .005 inches. For each succeeding pass the piece should be indexed .050 inches in the direction parallel to the length of the spot size. Each pass should be pulsed and indexed the same amount until the desired width of insulation has been removed.

The requirements for welding copper and gold plated leads and connector pins narrowed the choices of lasers to a **Neodymium:YAG type of laser.** The high reflectivity of copper to the wavelength of the CO_2 laser makes it highly impractical as a welding tool for this particular application. The power requirements can be readily handled by a 200 watt average power laser. This is a conservative estimate which allows higher production rates as the manufacturing technology progresses.

At the present stage of development, which is adequate to meet our automated production requirements, the welding is accomplished at a speed of approximately 24 in./min at a repetition rate of 16 pulses per second or higher. The present technique requires the accurate firing of the laser so that each lead receives two pulses approximately 4 joules each depending on the thickness of the conductors.

To ensure accurate energy density, uniformity of pulse shape and energy is required. This can best be accomplished by the use of an **oscilloscope to monitor** the operation and to facilitate adjustments. The scope can be a permanent part of the set-up whereby the operator can adjust the energy output to give a value to match the wave height and shape prescribed for a given task. This procedure will compensate for lamp degradation and can be used to detect abnormal operation of the equipment.

In development of prototype tooling, it was determined that the **tolerance on spacing** between parallel rows of connector pins was too great to allow effective clamping of the flexible circuitry to the connector pins on both sides of the connector at the same time. Therefore, one side is clamped, welded, and unclamped before the second side is clamped. A means of directing the focused laser beam in the horizontal plane and rotating it 180 degrees to scan each side of the connector is required.

The **positioning tables** are to be machine tool type, motorized, ball-nut and lead screw linear slide positioning tables. One axis, aligned with the rail should have a positioning range of 18 inches. The second compounded axis working at right angles to the rail should have a positioning range of 6 inches.

The **connector rail** is both figuratively and literally the backbone of the tool. It supports the Flexicon assembly in the vertical plane and provides unobstructed clearance for the flex circuit. Its thickness is scaled to receive the connector, with pin rows straddling the rail. This allows the connector to be moved to process positions along the rail by sliding motion.

The **radial arm** provides the means for inputting pre-oriented and stacked FPW and connectors into the automated system and for manipulating FPW through stripping and cleaning. It is positioned on the tooling table and in line with the input end of the rail. This strategic location provides access for the radial arm to the flex input, the connector input, the stripping laser and cleaning station, the transfer slides and the rail.

The two opposed laser beams have a common focal point. With the FPW held in place on the radial arm's vacuum platen, the FPW is aligned in the laser beam focal plane and programmed motion of the tooling table moves the FPW into the beam. The first pass causes a **strip of cover material** .062 inches wide to be ablated from both sides of the flex. To produce a wider stripped zone the radial arm is indexed upward .050 inch, presenting a new parallel strip of material to the laser beam on the return pass. The nominal .250 inch stripped zone required to register with the alignment comb used in the subsequent welding process would therefore require that five passes

be programmed with a .050 inch verticle displacement between each pass.

In the development work, a narrow margin of insulating material was intentionally left at the leading edge of the FPW. This selvage edge serves as a useful binder to retain the alignment of the exposed copper track through mechanical cleaning.

The cleaning process is necessary to remove particulate residue which might affect the absorptivity of the copper surface when presented to the subsequent laser welding process. A pair of soft, nylon bristle brushes are used to wipe away residue. The FPW is passed between the opposed pair of brushes immediately following the final stripping pass. A solvent wash completes the cleaning process.

In the design of **welding tooling** for flexible circuitry to connectors, for example, the surface must be uniform with respect to absorptivity of laser energy at the Nd:YAG wave length. In this particular case, the welding of copper conductors, where the insulation has been removed, a slightly oxidized surface not only absorbs energy more readily but also requires less energy to accomplish the same amount o melting. Also, the surface must be free of any contamination, specifically organic materials. This type of contamination vaporizes during welding causing changes to the opaqueness of the plume and thereby influencing the energy density and results in unsatisfactory welds.

In regard to **fixturing and joint designs** for example, metal to metal contact is important; the parts should be held in intimate contact for a length of 1/16 to 3/32". Selvage thickness should be the minimum width possible and the width of the stripped area should be wide enough to permit uniform pressure at the contact points.

Welding is done "on the fly" using a CNC programmable controller that controls the motion of the part as well as the pulse rate firing of the laser. The laser shutter is closed initially when the firing starts to allow stabilization of the pulsing output. Pulse rates are such that each conductor receives a minimum of two pulses.

After welding, the **inspection** of the welds for sufficiency can be performed on 100% of the joint by four basic techniques. These are resistance check, visual pattern recognition, acoustical emission, and laser thermal inspection. Laser Thermal Inspection is the observing of the thermal signature of weld joint after being hit with a laser beam. Acoustical Emission involves the bombardment of the welded joint ultrasonically and observation of the response. Optical inspection, or pattern recognition, would involve the optical scanning of the finished joints. The simplest method would involve a resistance check of the weld.

Of these four basic approaches, the continuity test approach is the simplest, least expensive to implement. If a noncontact approach is desired, then the pattern recognition could also be implemented.

Assembly Indexing

In order to progress the assembly through successive steps, a method of periodically fixing their positions in space while the rail is translated beneath them to the next station is required. A rod, oriented horizontally above the rail and supported in the Nd:YAG laser column, provides the fixed reference stops. These stops are radially mounted pins positioned along the rod at each connector spacing interval.

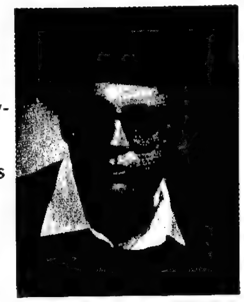
When indexing is to occur, the rod is first rotated to orient the pins in the space between the connectors. The position of these pins relative to each other determines the pitch interval which results, and should be held to a plus or minus .001 inch tolerance, nonaccumulative, along the rod axis. Maintenance of precise pitch interval assures the required registration with station features in the rail.

The purpose of **molding** of the welded flexible printed wiring/connector assembly is to provide mechanical strength of all the components and to provide protection against environmental contaminants. The system selected for encapsulation is reaction injection molding using a hydantoin epoxy resin system. The system is lightly loaded with a mica filler to help seal the mold against leakage and to improve release of the molded connector from the mold. The hydantoin epoxy provides excellent adhesion to all the components at the same time providing electrical insulation and protection against moisture. The prepared compound is injected into a mold which is preheated to 150 C and is held there under light pressure for about 5 minutes or until strong enough to demold after cooling using ejection pins.

he molding equipment design features considered were: flatness and sealing of the mold, injection port design, gating and venting of the multiple molds, heating and cooling of the mold, mold release and ejection mechanism, and clamping press for the mold.

Reliability Near 100 %

Welding Wire Inspected Faster, Better



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A new level of proficiency in high speed welding wire inspection during fabrication has been attained. Working on a project funded by the U. S. Army Tank Automotive Research and Development Center, Battelle Laboratories in Columbus, Ohio has developed a high speed method for nondestructive inspection of flux core wire. Voids as short as three inches are estimated to be detectable at rates of up to 700 feet per minute. The reliability of this eddy current method was shown to be $98 \pm 2\%$ at the 95% confidence level, and while some custom hardware was fabricated, much of the equipment is commercially available.

Considerable cost savings and pronounced technical advantages could be effected by replacing shielded metal arc welding with flux cored arc welding, since the latter operation is continuous and has a 2 to 3 times greater deposition rate. However, there is always the possibility of having sections of wire which are void of the necessary flux, with no change in external appearance of the wire to signal the welder to avoid the use of these sections.

Automated Welding Mandates New Tests

Due to the structure critical nature of armor welds and the advent of automatic welding equipment, nondestructive test equipment is becoming necessary which can operate with wire moving at any speed up to that used in wire manufacturing (about 700 feet per minute). Several wire manufacturers use speeds of 1000 ft/min. The 700 ft/min is the Army's requirement.

Material tested was Teledyne McKay's 3/32 inch diameter S115 flux core wire, which is suitable for high strength welds. The most used size of this material is the 3/32 and 1/16 inch diameters.

It is manufactured by feeding a mild steel strip onto a "tube mill" which forms the strip into a U shape. A measured amount of flux (19% of the total product weight in the case of Teledyne S115) is fed into the U-shaped strip. A series of forming rolls then closes the strip into a tube encasing the flux core.

The wire used in this program was specially fabricated by Teledyne McKay to contain a large number of intentional voids. Normal production wire was not used in this test.

Voids Thicken Walls

As this tube is drawn out to specified diameter, the loose flux compacts and serves as a mandrel which maintains the wall thickness at about 0.22 inch (for 3/32-inch S 115 wire). If the flux is absent (due to any one of several manufacturing problems),

NOTE: This manufacturing technology project that was conducted by Battelle Memorial Institute was funded by the U.S. Army Tank Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The TACOM Project Engineer is Mr. Buck Schevo, (313) 574-5814.

the wall thickness is not reduced as much for a given diameter of wire. The wall at a void in 3/32-inch S 115 wire is about 45% thicker. Figures 1-3 show, respectively, sections of good wire, wire with voids, and wire exhibiting transition from good wire to void wire. The inspection method uses eddy current coils to measure wall thicknesses greater than prescribed, thereby signalling sections of wire containing less than the necessary flux.

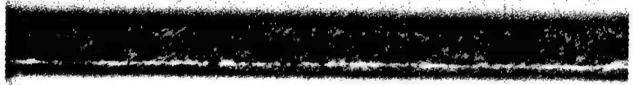


Figure 1

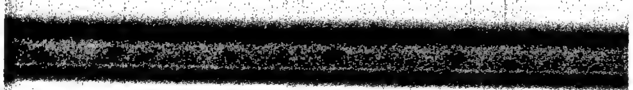


Figure 2

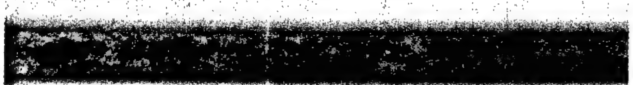


Figure 3

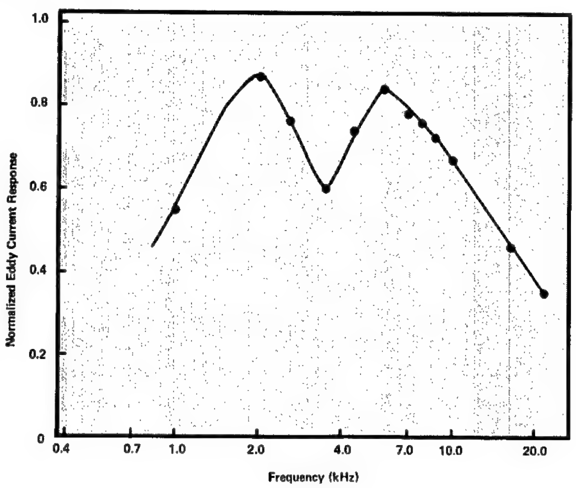


Figure 4

Test Frequency Critical

The effect seen by the eddy current coil is the sum of two competing factors: (1) an increase in coil inductance due to the presence of additional steel (thicker wall) and (2) a decrease in inductance due to a decrease in permeability (less cold working). At frequencies below 4 kHz, the former effect predominates, while above this frequency the opposite is true. Either the high or low test frequencies may be used (see Figure 4); however, the higher frequencies are affected more by "noise" from wire vibration (wobble) and localized carbon content variations. A frequency of 2 kHz was selected because of the peak in the curve at this point.

The instrumentation used is pictured below. Figure 5 shows the high speed test stand and Figure 6 shows the central test stand. The rear table holds the test stand controller (which operates the wire transport system) and the eddy current instrument. Virtually any phase sensitive eddy current instrument that is commercially available will perform satisfactorily. A flaw detector circuit with "threshold" settings provides a signal that can be used to activate an alarm or marking system. The coil, with its mild steel guide and aluminum housing, was fabricated for this application and was connected to the eddy current instrument through a BNC cable. A balance coil had a short section of similar wire which served as a reference specimen.

Method Proven Accurate

Tested, in all, were over 1½ miles of weld wire, with results verified by radiography. The test system found 100% of the 132 voids and showed that the results are very repeatable at speeds up to 700 feet per minute. Only one miscall (calling a void where there was none) in 7000 feet of wire occurred, and this was due to a kink in the wire.

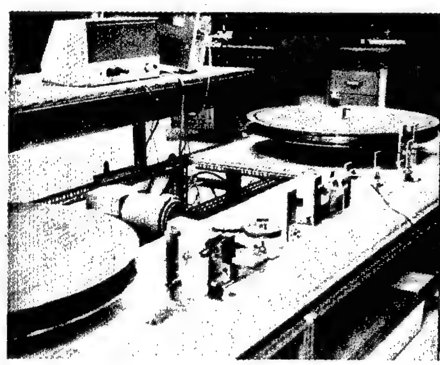


Figure 5

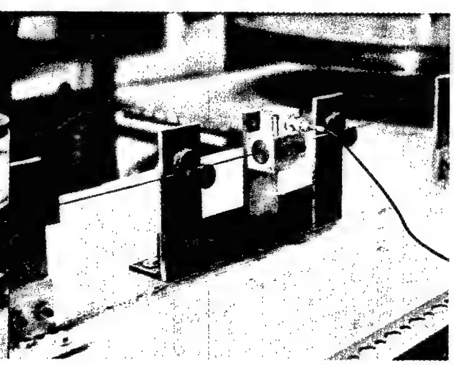


Figure 6

Rohan H. Phillips, an Assistant Professor of Manufacturing Engineering at the University of Illinois at Chicago Circle, directs the Manufacturing Engineering Program of the University's Department of Materials Engineering. Dr. Phillips' research and teaching interests center around computer applications in manufacturing, group technology applications, and the design and analysis of manufacturing systems. He holds a BS in Mechnical Engineering and an MS and Ph.D in Industrial Engineering from Purdue University, and is a member of AIIE, SME and ASEE.

Photograph

Unavailable

Software Development Vital

University Aid to CAM Research

Although hardware oriented research in the area of computer aided manufacturing (CAM) is beyond the resources of most universities, they can make significant contributions in the area of software development. This is demonstrated by ongoing research on computerized process planning at the University of Illinois at Chicago Circle (UICC).

Application of the UICC developed system, when it is completed, will save considerable time and expense in planning for computer aided machining operations. Already, the elements that are in place have proven effective in industrial verification studies.

The program output is an ordered list of machining processes applicable to a particular part. Now operated in a batch mode, the system will ultimately be ready for interactive operation.

Two Categories of Application

Outside research assistance such as this will become increasingly important to U.S. industry as many manufacturers look to CAM systems to improve the productivity of small batch production operations. Basically, computer applications in manufacturing fall into two categories—direct and indirect. In direct applications, a digital computer controls or monitors the production process. In indirect applications, the computer supports related activities but is not physically connected to the production process. Examples of indirect applications are computerized production and inventory control and computerized process planning.

CAM research tends to follow along these same lines. However, research in computerized process monitoring and control requires high capital investment in the form of modern, efficient machine tools and digital computing equipment—minicomputers, microprocessors, numerically controlled machine tools, adaptive control equipment, and the equipment necessary to interface the digital computer or controller and the machine tool. Computing equipment of this type is not readily available at most universities, and the allied interface equipment is very expensive to build. Thus, universities find research in this area generally beyond their means. Most of it is carried out by larger manufacturing companies.

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturing Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

Capabilities Match Need

On the other hand, development of computer software to support production related activities matches well with university capabilities and resources. Such research requires only the necessary expertise, a certain amount of manpower, and computer facilities that are available at nearly all universities. Generally, graduate students, directed by faculty members with CAM expertise, provide the necessary manpower. Some areas that can be considered for such research projects are production planning, inventory control, production scheduling, process planning, mathematical modeling and optimization of processes, and optimal allocation of resources. To illustrate what can be done, the current project at UICC is concerned with development of a computerized process planning system for machined components that are produced on both conventional and numerically controlled machine tools.

Time Saving Potential

In metal cutting operations, process planning has been found to be one of the most time consuming and costly steps in the entire manufacturing cycle. Present manual procedures result in long lead times, unnecessary production costs, non-standard process plans, and inefficient processing routes for most components. Computerizing the process planning activity will overcome these problems and allow development of efficient CAM systems.

UICC researchers have divided their development of a computerized process planning system for machined components into three main phases, as illustrated in Figure 1. Phase 1 involves developing a system to describe a machined part to the computer, just as an engineering drawing is used to describe a part for manual process planning. During Phase 2, the sequence of processes or machining operations needed to produce a part is determined. In Phase 3, detailed descriptions of each

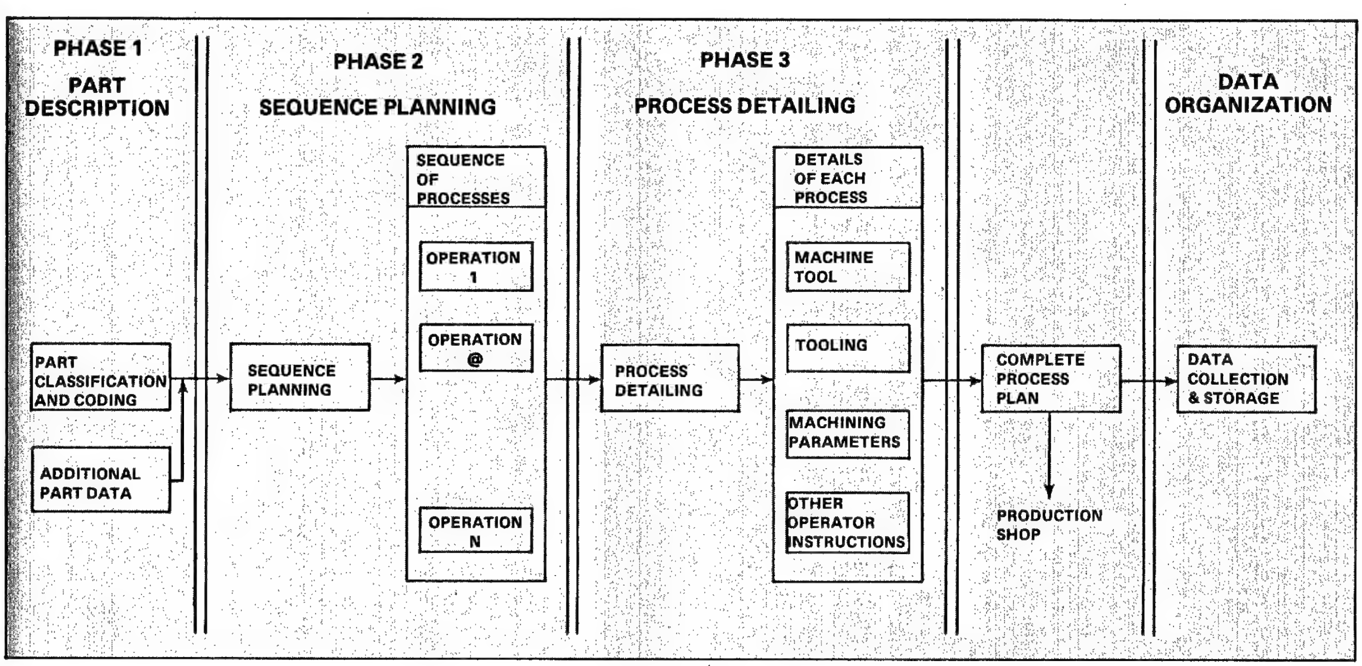


Figure 1

machining operation in the sequence are developed. These descriptions include such elements as machine tools to be used, cutting tools, and machining parameters. The final output from all three phases comprises a complete process plan. All the process planning data generated during the three phases are collected in a computer data base for use in subsequent process planning.

Approach Offers Advantages

Dividing the development of a computerized process planning system into these different phases offers some distinct advantages from a research point of view. First, it divides a very complex activity into smaller modules, each of which is easier to computerize. Second, the vast amount of part related information that is required for process planning is divided into smaller pockets of information in each phase of planning. This significantly improves the efficiency with which information is processed within the computer.

UICC has already developed a computerized system encompassing the first two phases of this approach. The system, presently being tested and fine tuned, is applicable to rotational machined components that are produced by the conventional machining processes shown in Figure 2. Parts are described by elements in an 18-digit classification code, shown in Figure 3. Additional part information, such as lengths and diameters of axial and non-axial holes and details of grooves, fillets, and chamfers, is included with the part code to complete the data input to the computer.

Lists Applicable Processes

Based on this input, the computer program systematically analyzes part geometry and surface finish requirements and generates a list of processes that are capable of producing the part described. The program then compares process capabilities with part tolerance requirements and eliminates processes that are incapable of meeting required tolerances. Applying well established processing hierarchies which are included in the program, the computer generates an ordered list of machining processes for producing the desired part, as illustrated in Figure 4.

PROCESS NUMBER	PROCESS
1	Turning (Conventional Engine and Turret Lathe)
2	Turning (Swiss Automatic)
3	Turning (Screw Machine)
4	Milling
5	Planing
6	Shaping
7	Slotting
8	Drilling
9	Reaming
10	Boring
11	Threading
12	Broaching
13	Grinding
14	Honing
15	Lapping
16	Gear Hobbing
17	Gear Shaping
18	Gear Generating

Figure 2

At present, the system is partially computer interactive—a part can be assigned a classification code number on an interactive basis. However, sequence planning has to be done in a batch mode, with an average of 6 to 10 seconds of computer time required for parts of medium complexity. Verification studies carried out in an industrial environment indicate that the system can produce accurate results and can be an effective manufacturing planning tool.

Position 1	: Main Category of Component
Positions 2,3	: External Shape
Positions 4,5	: Internal Shape
Position 6	: Auxilliary Holes
Position 7	: Gears
Positions 8,9	: Principal External Dimensions
Positions 10,11,12,13	: Workpiece Material
Positions 14,15	: Geometric Tolerance Requirements
Positions 16,17	: Dimensional Tolerance Requirements
Position 18	: Surface Finish Requirement
Main Class	1
External Shape	2 | 3
Internal Shape	4 | 5
Other Features	6 | 7
External Dimensions	8 | 9
Work Material	10 | 11 | 12 | 13
Tolerances	14 | 15 | 16 | 17
Surface Finish	18

Figure 3

Current Focus On Process Details

Present research activity centers on Phase 3—process detailing—and is geared to developing computerized procedures for each of the 18 processes. Initial studies focus on turning, milling, and drilling, because of the relative importance and high usage of these processes. To develop the processing details, UICC categorizes any machined part into certain basic geometries that are produced by different processes. For example, either external rotational surfaces produced on an engine lathe or drilled holes can be divided into certain basic categories. Computer routines being developed at UICC will analyze these

STAGE OF PROCESSING	PROCESS ALTERNATIVE	PROCESS NAME	CAPABILITY RATING
1	1	TURNLATHE	70
1	2	TURNAUTOSM	82
2	1	MILLING	90
2	2	PLANING	87
2	3	SHAPING	87
3	1	DRILLING	75
4	1	BORING	75
5	1	SHAPING	87
5	2	BROACHING	88
6	1	DRILLING	75
7	1	HOBBING	100
7	2	GEARSHAPING	100
8	1	GRINDING	100
8	2	LAPPING	100

NOTE: Based on an analysis of the workpiece code and other input information, the above processes are found to be feasible for producing the workpiece.

Figure 4

basic geometric models and generate detailed processing information for each process.

As the system develops, the research results are constantly validated through industrial applications in order to get as much practical input as possible into the system and into the final results. UICC is also working toward making the entire system interactive.

This program has demonstrated how universities without manufacturing equipment resources can contribute to CAM research. Research projects concerned with the analysis of manufacturing systems and the development of software for CAM are much needed and fit well in the university research pattern. There is no doubt that the results of such research efforts will contribute significantly to eliminating manufacturing productivity problems.

Nonetheless, manufacturing educators often find it extremely difficult to obtain funding for such research. An often heard remark is that manufacturing research is not basic enough to be funded by the federal organizations that support scientific research. What is needed then is government and industry recognition of the contribution that universities can make to applied manufacturing research, which could lead to a cooperative effort among government, academia, and industry to solve the country's manufacturing problems.

Emphasizes Latest Technology

Penn State Program Pushes CAM and Robotics

With automation looming as the manufacturing technology thrust of the '80s, the Pennsylvania State University Department of Industrial and Management Systems Engineering has geared both its instructional and research programs to meet industry needs in the areas of computer aided manufacturing (CAM) and robotics. Looking to rapidly arising demands for automation technology, the department has acquired several microprocessors, an industrial robot, and a CNC machining center. Through these facilities and faculty expertise, students in the department are constantly exposed to the latest manufacturing technology. In addition, the equipment has enabled Penn State to initiate several vigorous research efforts in robotics and CAM technology.

Since its inception in 1908, the Department of Industrial and Management Systems Engineering has stressed involvement in manufacturing technology, traditionally focusing on such processes as metal casting, metal cutting, metal joining, and deformation. Its laboratory facilities in these areas have served undergraduate instructional needs and provided a valuable resource for graduate education and research.

In 1956, the department added an Automation Laboratory for development of low cost automation equipment for industry and instruction in such topics as workplace automation and numerical controlled machining.

Now the advent of the microprocessor and the emergence of industrial robotics have sparked a startling transformation in manufacturing engineering at Penn State marked by the recent equipment acquisition and new research directions. Current research in the department touches on several key areas with potential benefits to industry.

Dr. William E. Biles, who heads the Department of Industrial and Management Systems Engineering at The Pennsylvania State University, has developed particular interest and expertise in systems optimization, process experimentation, computer simulation, material handling systems, and integrated manufacturing systems. He has been Director of the Operations Research Division of AIIE, and is active in ASEE, ORSA, TIMS, and NSPE. He also serves on the College-Industry Council for Material Handling Education. Dr. Biles received his BS from Auburn University, his MS from the University of Alabama in Huntsville, and his Ph.D. from Virginia Polytechnic Institute and State University. Before joining the Penn State faculty, he spent 7½ years in industry with Union Carbide Corporation and Thiokol Chemical Corporation and was on the faculty at the University of Notre Dame for 7½ years. He has autored two books and numerous journal and conference papers.

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturing Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

Four Primary Thrusts

CAM research at Penn State concentrates on four general areas:

- The development and analysis of special automation devices for feeding, prepositioning, and positioning parts to machines.

- The integration of industrial robots and specialized automation devices into microcomputer controlled manufacturing systems.

- The development of computer automated process planning systems that link CAD (computer aided design) and CAM files and automatically schedule parts and materials through a group technology based machine center.

- The development of specialized computer simulation and modeling languages that permit designers to analyze complex automated manufacturing systems before money is spent to build and operate them.

Research in these areas has been sponsored by government agencies—the U.S. Army, National Bureau of Standards, National Science Foundation; and by private industry—General Electric, TRW, Eastman Kodak, General Motors, and other companies engaged in automated manufacturing. The total annual expenditure for these projects now approaches $200,000, placing Penn State among the leading U.S. academic institutions in CAM research. A look at some of the specific programs gives a good picture of the capabilities at Penn State and the potential benefits to industry.

Part Feeding Improvements

In the United States, almost all workpieces for batch production are positioned manually—a practice that does not lead to improved productivity or profitability. If properly developed, flexible part feeding systems could change this picture and offer important productivity benefits.

Penn State's research in this area is directed toward developing design methodology for these flexible systems. The effort is broken into four tasks.

- Determine and categorize system requirements that will give industry a tool for increasing productivity, decreasing dependence on manual labor, and producing economic benefits.

- Evaluate both present and anticipated capabilities and limitations of robots with vision systems, with tactile sensors, and with prepositioning devices for use with flexible part feeding systems.

- Extend research on prepositioning devices to better understand the techniques that should be employed and to determine the capabilities and limitations of these devices when applied in conjunction with robot-based systems.

- Assemble all this information into a design methodology that will yield systems meeting the requirements of particular manufacturing applications.

Attractive Alternative

Results to date indicate that the use of conventional parts feeders with flexible tooling is an attractive alternative to the vision systems frequently used with robots. For vision systems to be successful in an industrial environment, that environment must offer excellent lighting, little visual distraction, and extensive computational power. Furthermore, vision systems are expensive. Nonetheless, simple black and white, two dimensional vision systems have enjoyed some success in situations where the part can be recognized in only two dimensions and can be presented to the machine in a non-overlapping manner.

Work is now underway to evaluate the capabilities and limitations of different types of conventional part feeders for flexible feeding. Of 31 types evaluated, two offer considerable promise. The Penn State researchers are studying these two types further to determine when tooling is needed to position different types of parts. Such tooling has been classified as: servo-controllable tooling, manual quick change tooling, and not easily changed tooling. Based on these classifications, the researchers have identified part families that can be totally or partially positioned by the various categories of tooling. Results to date indicate that flexible part feeding systems based on conventional hardware are not only possible, but could provide the missing link in the concept of flexible manufacturing.

Future work will be devoted to the design, fabrication, and evaluation of microprocessor controlled

hardware for prepositioning small parts for robotic handling. This work is based on the premise that productivity gains can be achieved by having auxiliary equipment preposition parts while a robot places them in the machine.

Automating Tool Grinding

Research is also under way at Penn State to develop automated equipment for sharpening twist drills. The latest 16-bit microprocessors are being employed as multiaxis machine tool controllers. The objective is to minimize use of electrical hardware and place as much of the automatic control function as possible with computer software. This approach should sharply reduce the cost of tool sharpening equipment.

At the same time, versatile computer controlled machine tools are under construction to replace all mechanical machine tools. When fully developed, such tools will reduce machine cost by minimizing the number of mechanical parts.

Ongoing research is also directed to developing improved mathematical models of cutting tools, especially twist drills. The objective here is to improve the repeatability of drill performance.

Group Technology Stressed

Group technology has long been a vital area of research at Penn State (see ManTech Journal, Vol. 3, No. 1, p. 42). To support this research, a manufacturing data base has been established using industrial data obtained from real world group technology applications. This data base is used to:

- Examine applications of cluster analysis techniques for finding manufacturing and design similarities that may be exploited through group technology.
- Investigate production flow analysis as a planning tool in manufacturing.
- Develop computer simulation models of group technology based manufacturing facilities for evaluating scheduling methods, plant layout alternatives, and material handling systems.
- Develop computer analysis of part population, shop workload distribution, and part flow.

Currently, a research project is underway for the National Bureau of Standards to develop software and information bases for determining part population and workload distribution, in the NBS shop. In determining workload distribution, alternative approaches to implementing group technology in the NBS shop will be evaluated using various group technology manufacturing criteria. This information will be used by NBS to design a flexible group technology manufacturing cell utilizing the latest in computer control, NC machining, robotics, and automated material handling systems. Anticipated continued research work with NBS will be directed toward a futuristic system termed as a "Flexible Group Technology Manufacturing Cell".

The Penn State researchers are also involved in development of computer aided process planning. One major result has been the development of a modular, semi-generative, interactive software system known as ACAPS (Automatic Computer Aided Process Selection). The different ACAPS modules address many planning aspects such as classification and coding, primary process selection, operation sequence generation, and part family formation.

Group Scheduling Improved

Penn State is now expanding and improving its group scheduling computer programs. To begin, the original program logic, written in BASIC, is being translated into FORTRAN. With this change, the group scheduling package can be implemented on almost any interactive computer. Furthermore, Penn State's heuristic model is being expanded so that the programming package can handle any group scheduling situation. Finally, data base interfacing to generate production times for the heuristic model is being investigated. Although any particular installation of the group scheduling package would need its own interface, it is important to identify and describe the necessary program changes so the package can be readily adapted to any installation.

Penn State researchers are also assessing different approaches to solving the static flow shop scheduling problem, with particular reference to a group technology context. This study focuses on the heuristic approach, which seems to be the only approach that accomodates different aspects of the

real industrial world. At the same time, the Penn State researchers are developing a procedure that halts research of new schedules when the cost of computation exceeds the expected gain.

Optimizing Manufacturing Systems

There are three major production criteria in manufacturing optimization—the maximum production rate (minimum time) criterion, the minimum cost criterion, and the maximum profit rate criterion. These three criteria are employed according to the manufacturing objectives. Where priorities must be established among these objectives or compromises made, multiobjective optimization (primarily goal programming) is conducted. The analysis covers both single stage manufacturing systems and multistage manufacturing systems in which many machine tools are sequenced in a technological order. The Penn State approach treats both single and multiproduct production from the standpoint of the number of part types to be machined. For a multiproduct manufacturing system, a group technology production system is analyzed.

Goal programming is now being applied to manufacturing systems based on a group technology concept. Production flow analysis and lot size analysis were selected for further study to optimize the approach. Since there are several conflicting objectives in grouping machines and parts, no totally optimal grouping can be obtained with the single objective optimization approach. Therefore, the problem is to determine optimal machine groups and part families, considering operation information under multiple objectives. For size analysis, the problem is to determine optimal batch sizes and decide the production cycles or the order of production under various kinds of criteria.

Cluster Analysis Techniques

Cluster analysis is a mathematical technique for finding similarities in large data sets. When properly applied to a manufacturing data base, this technique will identify cluster, i.e., component part families and machine cells, that will facilitate better manufacturing system control and optimization using group technology methods. Present work in this area is directed toward developing single and multiobjective cluster analysis methods for use with data from industrial group technology applications.

CAD/CAM Interface Problem Attacked

In the process of designing, manufacturing, and maintaining a product and its component parts, many individuals or departments contribute to and extract information from a central pool of manufactured parts data. The amount of data grows as:

- The basic design evolves in the drafting stage.
- Manufacturing procedures are designed, material supply is detailed, and machine or process availability is scheduled.
- Documentation and control material is published.
- Products and component parts are delivered and maintained.

This vast body of related data and information represents a familiar management problem encountered in all areas of engineering design and production. Current attempts to solve it using computers lead to large, complex systems, often with semi-redundant data bases. All of these systems attempt to expedite and organize the flow of data from product design through the manuacturing process.

Every item is designed for interpretation by a certain type of specialist. The computer may **associate** different items, but is cannot **link** them because it cannot interpret their contents. Thus, there is a need for:

- An integral, complete data model of the product and part designs.
- A means to logically interrogate this model for both design and manufacturing purposes.

Modeler Meets Need

Meeting the first need requires a geometric modeler. In a modeler based system, the one authoritative record of the design is the stored "model" and not drawings, which become subordinate. The

essence of the model is simply that there is only one. It can contain, or have linked to it, all the associated information required by design and manufacturing subsystems and is in a form that is interpretable or viewable for use. Unlike, the drawings in a drawing-centered system, the model cannot be understood directly by a human user; it is a computer oriented representation of the object itself, not—as with a drawing stored in a computer—a representation of a representation.

Logical interrogation of the geometric modeler to meet the second need comprises the CAD/CAM interface. Penn State researchers are attempting to develop a scheme for characterizing CAD/CAM interface systems along group technology concepts. The objective is a generative, interactive system that will produce hard copy on demand.

Developing Automated Systems Models

Another facet of the ongoing research in manufacturing engineering at Penn State is the development of quantitative modeling techniques for automated manufacturing systems. This research falls into two categories:

- Analysis of automatic transfer lines
- Development of a computer simulation language for modeling complex, integrated manufacturing systems.

Automatic transfer lines are typically very expensive, highly specailized, and inflexible. They consist of a series of simple machining operations, interconnected along a line or around a circuit, with workpieces transferred automatically from station to station. Cycle time is constant and geared to the longest machining operation in the system. The failure of one station shuts down the enire line, unless provisions are made for in-process storage between stations.

Since failure time and repair time are random variables, modeling of automatic transfer lines is a very complex task. At present, there are no analytical procedures for calculating production rate as a function of such parameters as the number and location of intermediate storage positions and the number of repair crews. The work at Penn State is presently focused on analytical modeling of systems with two stations, "n" in-process storage positions, and a single repair crew. Future work will be directed toward enlarging the problem that can be solved analytically.

Simulation Model Language Explored

For more complex manufacturing systems, analytical solutions are out of the question. The accepted approach is to resort to computer simulation modeling. There is a definite need for a specialized computer simulation language that incorporates the typical elements of a manufacturing system, so that an analyst can construct a model of a given system merely by combining selected elements. Such a language is under development at Penn State. Called MAP (Manufacturing Analysis Program), this language provides a set of blocks that are arrayed in a top down, scroll like fashion to describe the system under study. Designed to be especially useful with an interactive graphics terminal, MAP facilitates editing in its GPSS like modeling approach.

As the range of these programs indicates, manufacturing engineering at Penn State has experienced a remarkable transformation in recent years—progressing from the traditional focus on metals processing to the rapid emergence of microprocessor-based automation, robotics, computer aided manufacturing, and the powerful analytical and simulation modeling of complex manufacturing systems. These developments are incorporated in both undergraduate and graduate instruction, as well as in research programs. As a result of these developments, Penn State finds itself well postured for the automation thrust that is certain to characterize manufacturing engineering in the 1980s.

Acknowledgements

The contents of this paper are based on the efforts of the following faculty and researchers in the Department of Industrial and Management Systems Engineering at The Pennsylvania State University: Dr. William Biles, Dr. Inyong Ham, Dr. Dennis Pegden, Dr. Mark Fugelso, Dr. Jerry Goodrich, Mr. Gary Maul, Mr. Vincent Bond, Mr. Souemon Takakuwa, Mr. Mehmet Savsar, Mr. Terry Gongaware, Mr. James Taylor and Mr. Eugene Yang. Their contributions to this paper are gratefully acknowledged.

A Better Match Than Aluminum

Composite Bonds Improve Thermal Integrity

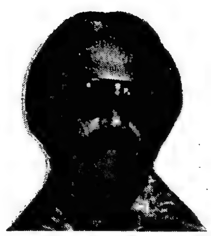
Stabilized line of sight gimbals have been proven producible that will result in better matchup of component parts when subjected to thermal cycling as a result of an MM&T program carried out by Westinghouse for the U.S. Army Avionics Research and Development Activity, Ft. Monmouth, New Jersey.

Existing and planned aircraft increasingly include electro-optical systems and sensors. Although these systems and sensors each are unique, they generally share the requirement for a stabilized platform. These platforms are generally two or three axis gimbal mounted subsystems which, because of the uniqueness of their payloads, are redesigned and remanufactured for every electro-optical system or sensor. Even in the example of a product improvement program for an electro-optical system currently being manufactured, the improvements usually are constrained to changes that do not impact on the stabilized platform.

The manufacturing techniques and tooling evolved in the present program have made it possible in a cost effective and timely manner to accommodate payload variations. The resulting stabilized platform is lighter and possesses better damping characteristics, while simultaneously giving the system developers increased flexibility for design changes. Also, the tooling techniques and unit shape fabrication will reduce production costs as well as provide greater platform compatibility between various electro-optical systems and sensors.

Work undertaken to design the azimuth gimbal structure was continued under this program with major effort directed at (1) the fabrication and test of the thermal sample, (2) completion of the engineering drawings of the azimuth gimbal confirmatory samples and the fabrication of the samples, and (3) development of a 1000 part per year production plan.

NOTE: This manufacturing technology project that was conducted by Westinghouse Electric Corporation was funded by the U.S. Army Avionics Research and Development Activity under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The AVRADA Project Engineer is Mr. Al. Kleider, (201) 544-4776.



ALFRED KLEIDER is a Physicist with the Sensors Branch of the Aviation R&D Activity (AVRADA) at Fort Monmouth, N.J. After 19 years of industrial experience, he joined the avionics Laboratory in 1972. Since that time he has been involved in a variety of electrooptical system developments for environment sensing applications. He has a B.S. in Engineering Physics and an M.S. in Physics from the University of Oklahoma. He has authored 13 papers and has 5 patents to his credit.

JAMES T. JOHNSON is the Program Manager of the Westinghouse MM&T for Stabilized Line of Sight Composite Gimbals. He holds a B.S. in Mechanical Engineering from the University of Illinois. For the past six years he has been responsible for manufacturing and process engineering functions as a Supervisory Engineer at the Westinghouse Defense and Electronic Systems Center in Baltimore. Prior to that, he was active in the mechanical design of airborne systems, including electro-optical systems. Mr. Johnson is a Registered Professional Engineer in Maryland.

ROBERT L. KOLEK is a Fellow Engineer with the Westinghouse Marine Division, Sunnyvale, California. He has 20 years of research experience in fiber technology, reinforced plastics, and polymer technology. He has been involved in fibrous composite development programs for a variety of Westinghouse business areas. He has authored numerous papers and holds six patents. Specific technical areas in which he has worked included undersea mechanical systems, aerospace electrical equipment, large turbine generators, and missile launch systems. He has been closely associated with the successful development of the Graphite/Epoxy MX Missile launch tube. Mr. Kolek received his B.S. and M.S. degrees in Chemistry from the University of Pittsburgh.

Bearing/Bore Thermal Match Essential

The thermal sample was designed to facilitate the evaluation of the thermal expansion characteristics of the bearing housing portion of the gimbal and to determine the effects of thermal cycling on the bonded composite to composite and composite to metal structure.

In a gimbal design of this nature, it is desirable to thermally match the bearing bore to the bearings as closely as possible. This helps maintain constant friction and stiffness values over the operating temperature range of the system.

The basic design concept is based on bonding the composite parts together with minimal loss of the advanced composite inherent properties. Many small samples were tested during the design phase to ensure that this would be the case. However, verification of the capability on a larger and more intricate sample was considered necessary prior to building the actual confirmatory azimuth gimbal samples.

The thermal sample was designed as shown in Figure 1. The configuration closely represents the central portion of the confirmatory samples. Figure 2 shows the top and bottom views of the Thermal Test Sample.

During the thermal tests, it was determined that the thermal coefficient of expansion of the bearing bore was 4.52×10^{-6} IN/IN/degree F over the temperature range of -14 to + 162 F.[1] This compares to 5.6×10^{-6} for the bearings and provides a better match than in the aluminum gimbal upon which the composite design is patterned. Both designs employ a titanium ring that interfaces with the outer bearing race.

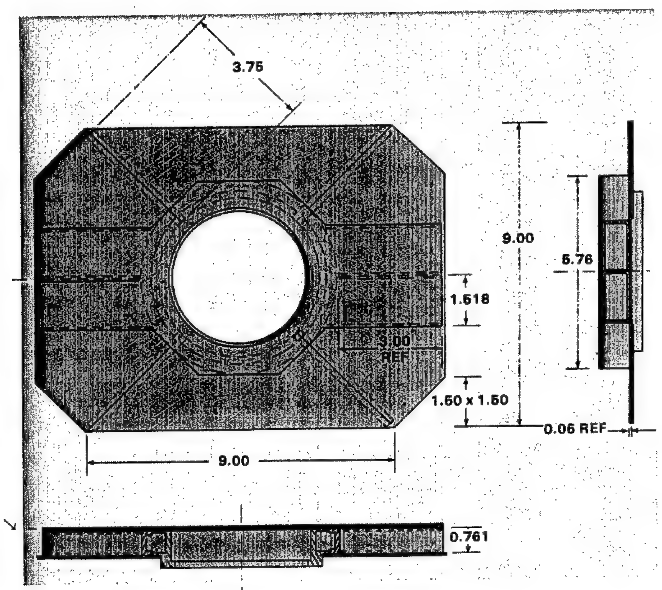


Figure 1

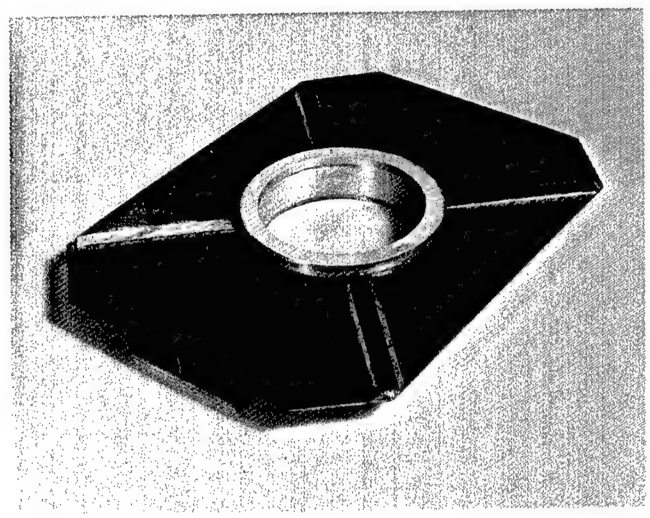


Figure 2

The thermal cycling tests of the bonds was conducted using progressively lower temperatures so that if degradation occurred, the temperature causing the degradation would be documented. The first cycle was at -20 to + 160 F. The final cycle was at -65 to + 160 F.

To determine if any degradation had occurred during the tests, the beam stiffness of the part was checked before and after each set of temperature excursions. Figure 3 shows the three point bending test setup in the Instron tension/compression tester. The results indicated that no loss of stiffness occurred and therefore it was concluded that the bonded joints were not adversely affected by the temperature extremes.

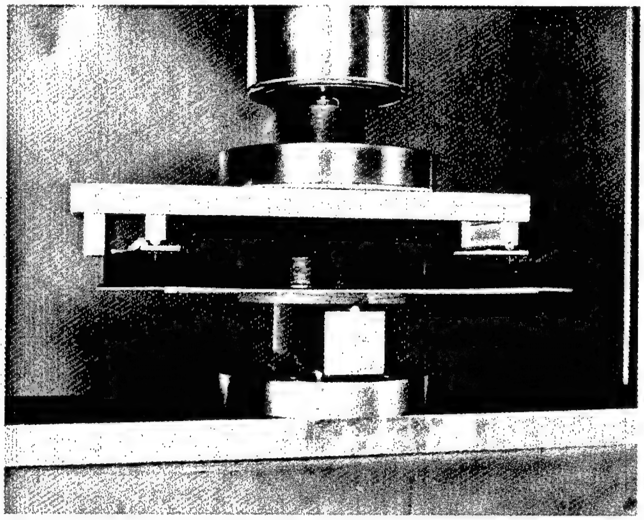


Figure 3

Design Changed Confirmatory Samples

The design was completed with three changes from that discussed on Page 42. The structural integrity of the main gear box was increased by lowering the top level of the box to the level of the bearing support ring and extending the cap plate over the gear box. The primary effect of this change is to greatly increase the stiffness of the joint between the gear box and the bearing support ring. Additionally, the gear box design change permits the use of the "standard" tubes already used for the actuator support arm and synchro box instead of requiring a unique tube.

The connecting structure between the vertical part of the arm assembly and the bearing support ring has been changed so that the small cross section tubes originally included are no longer needed. The tubes are replaced with a fabricated structure of longitudinal stiffeners and flat plates. While actually increasing the stiffness of the structure, the design change also eliminates the potential problems associated with the manufacture of the mandrel for the small cross section tubes.

Base Plate Stiffener Ring design was done to effectively incorporate the threaded insert approach that is to be used with the ring. Also, the weight of the ring was reduced while the strength and stiffness were maintained. The ring is now a winding with scalloped pockets cut into the perimeter for weight reduction.

Also, stress calculations were made of the primary joints between the gimbal arms and the bearing support ring. As expected, the margins of safety with the anticipated vibratory loadings are high in these areas.

The assembly layout of the gimbal is shown in Figure 4. For comparison purposes, a photo of the aluminum version of the gimbal (casting) is shown in Figure 5.

Fabrication Involves 121 Parts

The design is made up of 33 items or styles of parts. The total parts count prior to assembly is 121.

The 30 styles of parts were organized into 5 categories as follows:

1. Box Sections
2. Plates
3. Windings
4. Individual Fabrications
5. Metal

The box sections of rectangular tubes have to have good external surface finish to facilitate alignment and bonding to other parts during later operations. Therefore they were formed on expandable internal mandrels. After these mandrels were wrapped with Courtauld's 10K HY-E 1248-1A graphite prepeg at the proper angles such as ±25 degrees, ±45 degrees and/or ±90 degrees, the mandrel was positioned inside a form tool and then expanded. After curing, the external form was dissassembled and the internal mandrel contracted and removed. The box section was then machined for the next operation.

Twelve plies of Courtauld's HMS 10K HY-E 1248-1A graphite oriented at ±25 degrees and Fiberite 984A1 epoxy resin were used to produce the .063 thick plates. These were cured in an autoclave at 100 psi and 250 F. The other thickness plates were fabricated using the appropriate ply counts and angles as required by the drawings.

Two parts were fabricated using filament winding combined with manual layup. These parts were the Bearing Support Ring and the Base Plate Stiffener Ring. These are shown as H16 and H 26 respectively in Figure 4.

The bearing support ring is made up of both composite material and titanium. The graphite/epoxy ring was fabricated in three parts and then bonded together using Hysol EA 9320 adhesive to form the circular channel section. Machining the composite part as a single piece was considered but it was believed to be too risky due to the thin flanges.

The web portion of the channel was constructed as designated by:

$$[90°_3/\pm45°/90°_2/\pm45°/90°_2/\pm45°/90°_2/\pm45°/90°_3]$$

The two flanges were constructed to:

$$[90°_3/\pm45°/90°_2/90°_3]$$

Hercules HMS fiber was used for the 90 degree layers and Hercules HMS-1908 prepreg was used for the ± 45 degree layers. The resin formulated for the 90 degree fibers was:

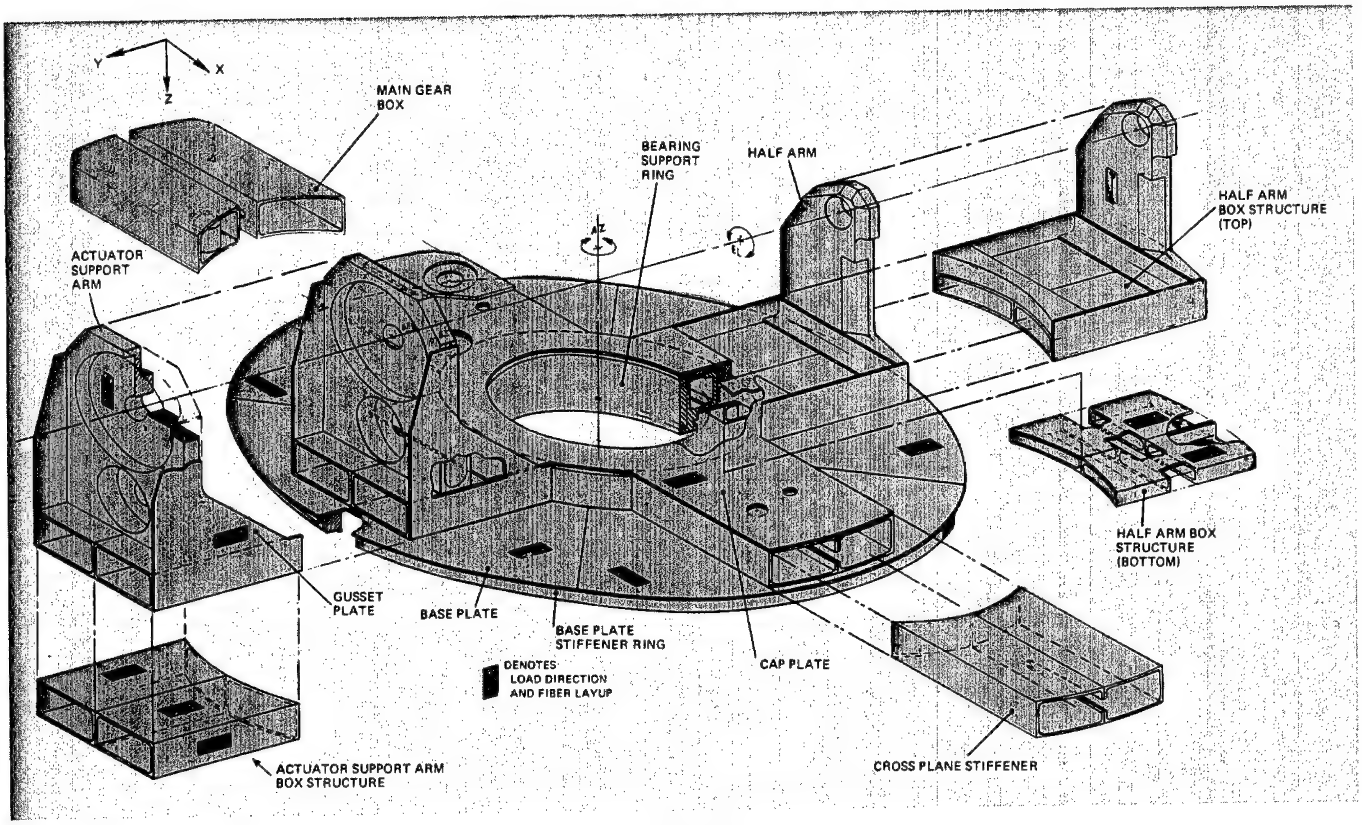


Figure 4

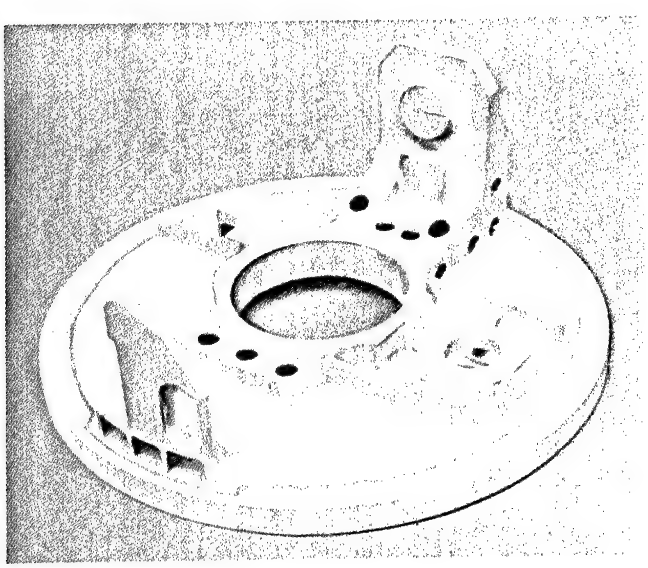


Figure 5

Epon 826	80 parts by weight
Celanese 5022	20 parts by weight
Tonox 60/40	24 parts by weight

Curing was accomplished using:

Gel	1 hour, 200 F; 1 hour, 250 F
Cure	2 hours, 350 F

Prior to bonding the composite and titanium parts together, the titanium was pretreated to improve bondability with PASA JELL SOLUTION in accordance with Section B-4-2 of the DOD/NASA Structural Composite Fabrication Guide, 2nd Edition, Vol. 2, dated May 1979, Ciba Geigy adhesive #XU225/205 was used for the bonding.

Precompaction for Porosity Impractical

Development of the fabrication procedures for the Base Plate Stiffener Ring required considerable engineering time.

The first test ring wound was constructed using only the Panex CFP 30-05 carbon fiber mat. The winding resin was of the following formulation:

Epon 826	—	80
Celanese - 5022	—	20
Tonox 60/40	—	27

The cure schedule was the same as noted above.

A W-60 McClean-Anderson filament winding machine fitted with an aluminum mandrel was used.

The all Panex CFP 30-05 winding attempted a 50 wt% resin content. The first trial was not successful and resulted in a dry composite. A second trial used a 70 wt% resin content and resulted in a well bonded but highly porous composite part. A third trial was attempted using a Mylar shrink tape overwrap to compact the layers and eliminate the porosity. This trial was unsuccessful due to buckling of the internal mat layers as the shrink tape applied external pressure and the layers of mat were forced to decrease in diameter. It would have been possible to eliminate the porosity by precompacting the mat layers in stages and trials were conducted to demonstrate this method. The time required, however, was considered to be excessive and the all mat approach was abandoned.

A second ring was fabricated using the alternating Panex CFP 30-05 mat and AS-412K continuous fiber approach. The construction used was as follows:

$$[\text{Panex CFP}_2/90°_2]_{12}$$

This ring was wound using 70% by wt. of resin in the mat layers and 30% by wt. of resin in the AS-412K layers.

The measured thickness of the as wound layers were as follows:

Panex CFP 30-05	(2 Layers) 0.010 inch
AS-412K	(2 Layers) 0.020 inch

The continuous 90 degree layers of AS-412K fiber were applied with a tension of 5 lb per tow. Two tows were used for the winding, giving a band width of 0.15 inches. The wound part used the same resin and cure schedule described previously. The OD was measured at 13.00 inch. The ring was edge trimmed with a diamond cutoff saw and examined visually. Excellent composite compaction was achieved. The void content was measured at 3.5% and the resin content at 45% by wt.

A second backup ring was fabricated in the same way as the one just described except that a tension of 8 lb per tow was applied to the AS-412K fiber. The higher tension was used in order to achieve greater composite compaction in the event machining problems were encountered with the second ring. Wet weight measurements on the as wound layers removed from the mandrel indicated a resin content of 40% by wt. This data point indicates that greater consolidation and lower void content was achieved. It was not necessary to utilize this ring for machining purposes.

Two finished rings were produced from the second as wound ring. This operation was viewed primarily as a milling operation which required continual support of the composite part during the milling and drilling operations. Two 0.41 inch wide rings were wet cut from the as wound part using a diamond cut off wheel.

Aluminum support tools were fabricated to fixture the composite rings for the milling operations. Solid carbide four flute routers were used for the milling operation. The called out holes were predrilled using carbide drills and were used to attach the composite ring to the aluminum bed plate. All of these operations were done dry.

Production Total 1000 Units/Year

The contract includes the development of a production plan to fabricate 1000 gimbals per year with design changes expected every 100 to 200 units. Work on this plan has progressed in parallel with the fabrication of the confirmatory samples. The elements of the plan being developed are:

a. Facilities Requirements
b. Manufacturing Sequences or Flow
c. Material Requirements and Costs
d. Manufacturing Times
e. Material Costs
f. Tooling Requirements & Costs
g. Yield
h. Quality Control Procedures

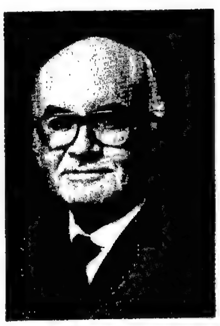
The plan is being based on obtaining all of the raw material in the form of prepreg tapes and tows from outside suppliers. All processing of these basic materials will be accomplished in the facility. Quality will be verified throughout the process and will include quality determinations after final assembly and final machining.

Low Cost Tooling Top Benefit

The azimuth gimbal can be designed using composite material with a resulting 33% weight reduction and improved functional properties. Manufacturing methods have been developed for the basic elements or shapes used in the manufacture of the gimbals. However, the real benefit is that the tooling used has been low cost and lends itself to periodic design changes without incurring high costs.

A Swing to the Future

Composite Gimbal Tooling, Fabrication Less Costly



WAYNE B. LLOYD is an Advisory Engineer at the Westinghouse Defense and Electronics Systems Center in Baltimore, Maryland, where his recent activities have been in the field of structural design and servo controls with concentration in the design and development of gimbals for electro-optical systems and radar. He also has been heavily engaged in the development of a benchless high energy laser employing active vibration control. Prior to that he was active in design of fluid power control elements including servo valves and actuators. A Registered Professional Engineer in Maryland and holder of B.S. and M.S. degrees in Mechanical Engineering from the University of Florida, Mr. Lloyd has 18 U.S. Patents and is the author of numerous technical papers and reports in his field.

THOMAS F. GRAPES is a Senior Engineer with Westinghouse Electric's Defense and Electronic Systems Center in Baltimore, Md. His current activities involve the design, analysis, and testing of mechanisms and electro-optical gimbal systems. He has had a continuing involvement throughout his career with experimental modal analysis and has worked with both Fourier techniques and a time-domain modal method. His work has moved toward finite element structural analysis from more hardware oriented tasks. He received his B.S. from the University of Vermont and his M.S. from the University of Maryland, both in Mechanical Engineering.

Design of the azimuth gimbal structure was undertaken initially so that a weight savings would result. It was also hoped that resonance frequencies of the redesigned gimbals would be equal to or greater than those of the aluminum gimbals currently being used. Both goals were achieved using advanced composite material construction and low cost tooling. Specific task areas included load analysis (to determine optimum filament orientation), development of subelement fabrication techniques, and resolution of bonding problems. In addition, approaches were developed to maintain alignment during bonding and methods were selected for installing metal inserts.

In the past, gimbals were made from magnesium or aluminum, with aluminum having the greater strength. To produce aluminum gimbals meant casting them. If a design change was made, the casting also had to change—and this is both an expensive and slow, time consuming process. Use of the new composite material construction method, therefore, provides a flexibility in design change that never was available under the old manufacturing methods.

Structural Design Complex

In the composite gimbal structure shown in Figure 1, six of the subelements are displaced away from the main structure although the main structure is complete as drawn. The structure employs a base plate (the circular plate to which the azimuth yoke and the pressurized dome are attached) onto which the major structural elements are bonded. These bonded elements are the bearing support

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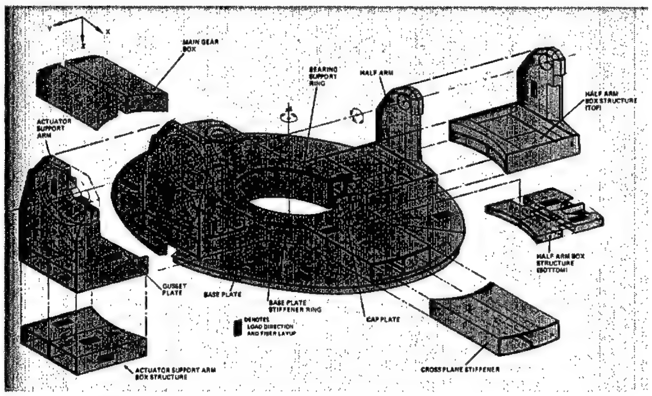


Figure 1

ring, the actuator arm box structures, the half arm box structures (top and bottom), the main gear box, the cross plate stiffeners, and the base plate stiffener ring.

The bearing support ring consists of a titanium inner ring, a composite outer ring, and a composite top plate which are bonded together to form a closed ring having a hollow section. The bearing support ring is bonded to the base plate and to the cap plate.

The actuator support arm box structures carry most of the load from the actuator support arm to the bearing support ring and have inboard ends contoured to match the radius of the bearing support ring. They are bonded to the OD of this ring and the joint is reinforced by the cap plate, which is bonded to the top of the bearing support ring as well as to the tops of the actuator support arm box structures. It will be appreciated that the joint between the box structures and the bearing support ring is in the form of a classical double strap joint, with the cap plate and base plate being the straps. A similar situation ensues where the half arm box structures (top) are bonded to the bearing support ring on the half arm side, although the cap plate area is not as great in this case.

The cross plane stiffener boxes (which serve as both stiffeners and housing for synchro gears) and the main gear box (which houses the azimuth drive gearing) are also attached to the bearing support ring by a double strap joint; however, Figure 1 does not show this double strap joint for the main gear box.

The two actuator support arm boxes are bonded together on the adjoining sides, and the actuator support arm, which is in essence a bulkhead with a broadened base, is bonded to the tops of the box structures. The actuator support arm is buttressed by gusset plates, one on each side, which serve to strengthen and rigidify the joint between the arm and the boxes in all three axes. Reinforcement of this arm is more critical than for the half arm because the rotatable elevation gimbal is axially anchored to the actuator arm while being slidably mounted in the half arm. The half arm supports the end of the elevation gimbal opposite the actuator end and which is adjacent to the stabilizing mirror. This arm is partially cut away to allow clearance for the mirror, hence the term "half arm". The half arm box structures (bottom) carry most of the load from the half arm to the bearing race support ring. They are bonded to the base plate, but are not attached to the bearing support ring.

Figure 2 shows the composite gimbal layout in orthographic projection with some features that do not appear on Figure 1.

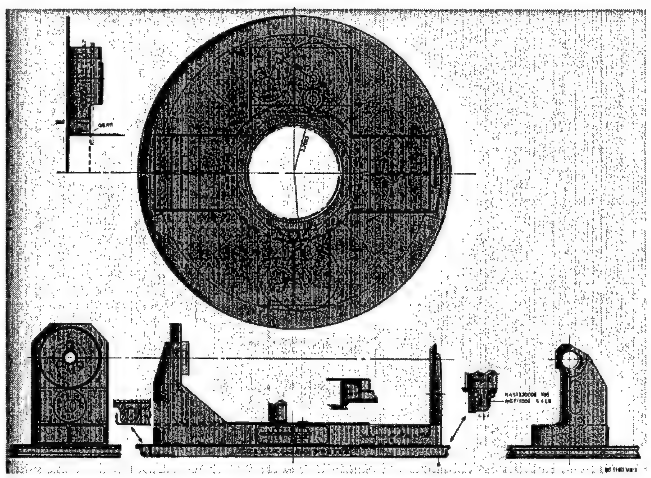


Figure 2

Filament Orientation

The actuator support arm boxes, the half arm boxes and the bearing support ring were the first parts to be designed to obtain sufficient rigidity to obtain the required resonant frequencies for vibration in the X, Y, and Z directions. For this requirement the boxes are subjected to both bending and torsion, which means that a good compromise between Young's modulus, E, and shear modulus, G, must be achieved. Plots of E and G versus θ, where θ is the angle between filaments and the load axis (grain), showed that a ± 25 degree layup will result in values of both E and G which are significantly higher than those for an isotropic layup. Subsequent calculations of the resonant frequencies, using the composite properties determined by the computer program SPACEWOUND for

the ±25 degree layup, confirmed that this is a good choice as compared to an aluminum structure (in terms of stiffness to weight ratio). This layup was found to be suitable for all the other box structures and thus became the most frequently used layup.

The base plate was designed to use the ±25 degree layup to achieve thermal expansion compatibility with the boxes to which it is bonded. To do this requires a four segment base plate with each segment having its load axis oriented as shown in Figure 1. The seams in the base plate will be reinforced by doubler plates on the bottom surface.

The total weight of 2.247 lb for the composite gimbal compares to a weight of 4.02 lb for the equivalent aluminum gimbal.

Circular Spring Theory Solves Problem

The configuration of the bearing support ring involves differential thermal expansion between the composite and the metal over a wide range of temperature. The differential expansion can induce shear stress which may break in the bond, and it can induce changes in curvature which may affect critical alignment.

Analysis of an assembly of two annular flat plates, one of titanium and the other of graphite epoxy composite, bonded together with high strength adhesive has shown that the problem can be solved using circular spring theory. In this approach, the rings are first considered to be of equal diameter and unattached. Thermal expansion is then allowed to occur, which causes the diameter of the titanium ring to become larger than that of the composite ring. This in effect reestablishes the free diameter of circular springs which are to be subsequently forced to have the same diameter. The rings are then assumed to be brought into diametral coincidence by a uniformly distributed, radially oriented array of relative force vectors which expand the composite ring and shrink the titanium ring. Using the ring spring constant for the two rings and equating the diameters, it is possible to solve for the shear force as a function of the initial difference in expanded diameters. The final diameter of the combined plates can also be determined.

For circular plates in a typical assembly, the thermally induced bond stress is only a few hundred psi for each 100 degrees F change in temperature. Since the adhesive has a shear strength of approximately 3000 psi, there is sufficient bond strength to avoid bond breakage over the normal range of temperatures encountered. Thermally induced warping may occur but it can be controlled by adequate moment of inertia of the sections of the joined materials.

The thermal characteristics of the bearing support ring and its adjoining structures will be studied experimentally by tests of a thermal sample. This sample will be subjected to temperature changes comparable to those expected in use, and measurements will be made of its rigidity and dimensional stability. The thermal sample will also serve as a structural sample useful in validating the structural analysis.

Resonant Frequency Analysis

A resonant frequency analysis was carried out for the current gimbal structure. The bearing support ring was assumed to be rigidly attached to a frame, which assumes infinitely rigid rolling element bearings. The model analyzed is shown schematically in Figure 3.

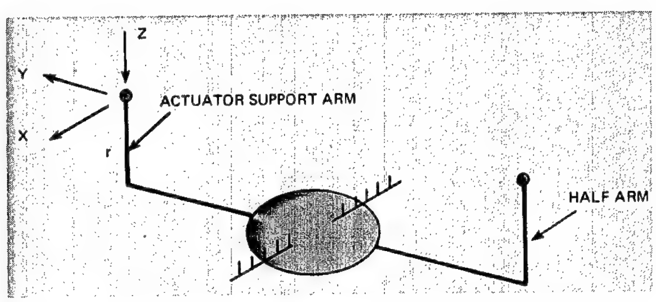


Figure 3

In the X direction, the spring rate at the end of the actuator arm is given by:

$$K_X = \frac{K_{RM}K_{BT}}{(K_{RM} + K_{BT})\, r^2}$$

K_{RM} = Torsional spring rate of the ring, lb-in/rad

K_{BT} = Torsional spring rate of the boxes, lb-in/rad

A similar relationship holds for the spring rate at the end of the half arm.

In the Y direction, the spring rate at the end of the actuator arc is:

$$K_Y = \left(\frac{K_B K_R}{K_B + K_R}\right)\frac{1}{r^2}$$

K_B = torsional spring rate at the end of the boxes, with respect to moments around an axis parallel to the X axis, lb-in/rad

K_R = torsional spring rate of the bearing support ring with respect to moments around an axis parallel to the X axis, lb-in/rad

r = length of actuator support arm, in.

In the Z direction

$$K_Z = \left(\frac{1}{K_B} + \frac{1}{K_{RFD}} + \frac{1}{K_T\theta/\ell_B} + \frac{1}{K_{RTD}/\ell^B} + \frac{1}{K_{RF}\theta/\ell_B}\right)^{-1}$$

K_B= displacement stiffness of beam (bending), lb/in.

K_{RFD} = displacement stiffness of ring to force, lb/in.

$K_{RT}\theta$ = rotational stiffness of ring to twisting torque, lb-in./rad

K_{RTD} = displacement stiffness of ring to twisting torque, lb/in.

$K_{RF}\theta$ = rotational stiffness of ring to force, lb/in.

ℓ_B = length of beam, in.

Spring rates with R in the subscript pertain to the bearing support ring which was treated as a curved beam using the Roark formulas for such beams. Owing to the complexity of the formulas, a Fortran code was written and used to analyze various cases for the design evolution. The spring rates with B in the subscript pertain to the box structures and were also evaluated using formulas from Roark. In some cases these formulas were programmed on a programmable calculator for better efficiency in carrying out design iterations.

The calculated spring rates were:

	Actuator Arm Side	Half Arm Side
K_x(lb/in.)	28,710	9,385
K_y(lb/in.)	12,646	N.A.
K_z(lb/in.)	17,520	9,792

Calculated F Well Above Minimum

The elevation gimbal was assumed to be a rigid body having I_x = .25 lb-in-sec^2, weight = 6.1 lb, $\bar{X} = \bar{Z}$ = O, and $\bar{Y}$ = 0.1 in. For vibration inputs in the X and Z directions this results in the classical case in which a rigid beam is spring suspended at each end with springs having unequal spring rates. The solution yields two resonant frequencies in each direction. For the Y direction, only one resonance exists. The results of this analysis are:

Input Axis	Frequency, F (Hz)
X	205.8,355.4
Z	201.4,289.8
Y	142.4

These calculated frequencies are well above the minimum requirement of 100 Hz, and all but the Y direction resonance are well above the 150 Hz design goal.

Tests of Material Samples

Tests of ten physical properties of HMS/1908 graphite epoxy composite were conducted at the Westinghouse R&D Center. The results of the tests along with the theoretical values are given in Table 1. The theoretical values were computed using the computer program "SPACEWOUND", which was developed at the Westinghouse R&D Center. The program uses as inputs, the resin and fiber properties along with the layup angles. The test values in the table are an average for 5 specimens for each category of test. Variation of test results between specimens was quite small; for example, the range of tensile strength was 7,100 psi compared to the mean of 60,000 psi, while the range of tensile modulus was 1.06 x 10^{+6} psi compared to the mean of 9.7 x 10^{+6} psi.

Test	Value Determined By Test	Predicted Value
Tensile (0 degrees)	60,000 psi	67,833 psi
Compressive (0 degrees)	44,190 psi	31,797 psi
Flexure (90 degrees)	60,050 psi	67,833 psi
Shear (90 degrees)	5,610 psi	12,235 psi
(0 degrees)	5,250 psi	12,235 psi
Density	1.5649 gm/cc	1.5875 gm/cc
Fiber Volume	57.02%	
Void Content	0.0%	0.0%
Hardness	55, 60, 60, 58, 57	
Tensile Modulus	$9.7 \times 10^{+6}$ psi	$11.6 \times 10^{+6}$ psi
Shear Modulus	Not Tested	$4.437 \times 10^{+6}$ psi
Thermal Coefficient Expansion	Not Tested	1.080×10^{-6} in./in./degree F
Poisson's Ratio (tension)	0.319	0.3072
Poisson's Ratio (compression)	0.300	0.3072

Table 1

Explanations of variations between the test results and theoretical projections have not been formulated. However, the variations are moderate and are not large enough to jeopardize the outcome of the design. Further work is currently under way and more is planned to achieve a greater percentage of the theoretical modulus of the composite material. Emphasis is being placed first on modulus because this is the driving factor in the gimbal design rather than strength, which is the usual case.

Graphite Epoxy Materials Tested

A series of material development experiments done in-house included the fabrication of flat plates of two different types of graphite fibers and two types of layups. Tubular members having a rectangular cross section (up to 18" in length) have been fabricated using bias cut and unidirectional graphite tape stock.

Physical tests performed showed that the measured values of bending modulus (E) were substantially lower than predicted. However, the measured values for P75S and GY70 both (0/90)s are quite good in terms of stiffness to weight ratio. The GY70 and P75S materials have very high modulus fibers and were chosen for this reason. The causes for the discrepancies between predicted and measured values have not yet been ascertained, but work is in progress to determine these causes. Possible explanations are excess void content, excess resin content, or fibers broken in the fabrication process.

Metal Inserts

Tests have been conducted on two types of threaded metal inserts suitable for composite materials. One of these, the bonded titanium cylinder, is shown in Figure 4.

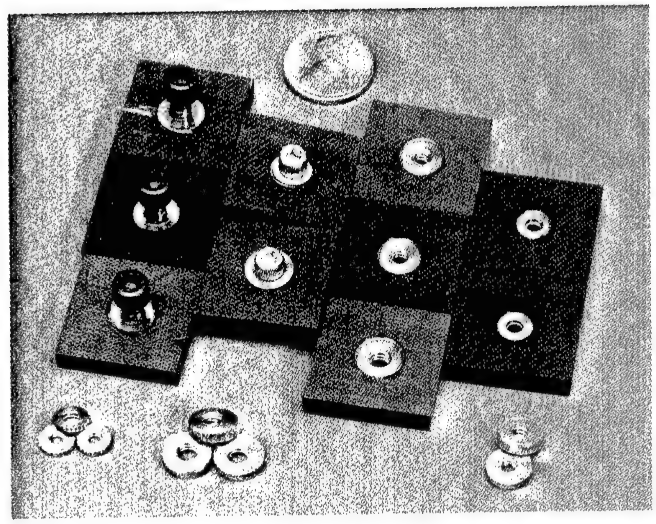


Figure 4

These are titanium cylinders having diameters equal to the dimension across points of the hex nut for the screw size involved and thickness equal to that of the nut. The outside diameters are serrated for better adhesion. Four samples of each of the screw sizes 8-32, 6-32, and 4-40 were made and tested. Two types of adhesive were used for each size of insert; namely, EA 9320 Hysol and XY235/XU215. The inserts were bonded into counterbores machined into 0.160 in. thick isotropic plates made by bonding together two 0.080 in. plates with FM 73 adhesive.

Torque tests were conducted on the specimens by installing a socket head screw so that the screw head bottomed out against the titanium insert. A zero-side-load torque wrench was used to attempt to measure the shear-out torque capacity of each of the inserts. This shear-out capacity was not determined because failure of either the screw threads in the titanium or the hex sockets occurred first. It can be stated from data that the shear-out capacity of the 8-32 inserts with either EA or XU adhesive is greater than 80 lb-in and that the shear-out capacity of the 6-32 inserts with EA adhesive is greater than 40 lb-in.

These are very favorable results which confirm the utility of the bonded titanium insert. It is expected that in practice, the titanium will not be used directly for threaded holes because of its relatively low hardness, rather the titanium cylinder will be used as the base material for a clinch nut type of fastener, combining the corrosion resistance of titanium and the durability of 303 stainless clinch nuts.

The second type of threaded insert tested is shown in Figure 5. Good results were obtained by using this standard commercially available fastener directly in 0.080 in. isotropic plate. The only modification necessary was the addition of a thin stainless steel washer on the side where the clinch nut sleeve collapses when being set.

Corrosion Resistance

Corrosion resistance is an important consideration in the mating of metals with composites; for example, aluminum is subject to galvanic corrosion when in intimate contact with graphite composites when moisture is present. Tests have shown, however, that titanium in contact with graphite does not show noticeable corrosion after long term exposure to corrosive conditions. Some of the threaded inserts used in the composite gimbal design will be exposed to ambient conditions in service. For these inserts, direct contact between the inserts (303 stainless) and the graphite composite is avoided by inserting the clinch nut type insert into a titanium wafer of the same proportions. The titanium wafer is then accurately located on the gimbal and adhesively bonded to the graphite composite. Inserts used in areas of the gimbal that will be environmentally controlled (under the shroud) will be inserted without the titanium wafer.

FM 73 Most Promising

The most promising adhesive for bonding the various structural parts to form the complete gimbal is the film adhesive, FM 73. Tests have been conducted to determine the shear strength and the rigidity of this adhesive. Manufacturer's data were available for the shear strength but not for the shear modulus.

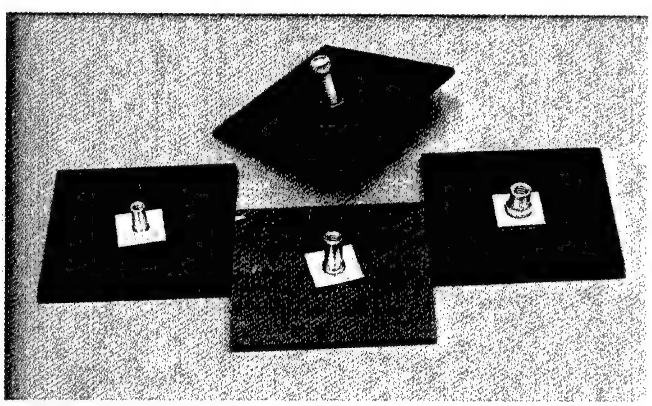


Figure 5

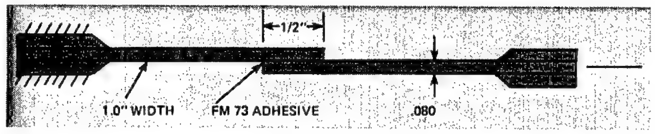


Figure 6

The shear ultimate for the FM 73 adhesive was tested using the standard lap shear test. The specimens were prepared as shown in Figure 6.

Four such specimens were tested to failure, but two of these were deemed invalid and are not reported here. The two valid tests resulted in failure loads of 1600 lb and 1220 lb or, when translated to shear stress, 3200 psi and 2440 psi, respectively. The manufacturer's test data listed 6400 psi lap shear at 75 F. The difference in the in-house lap shear and the manufacturer's lap shear is attributed to delamination of the adherend, which in the above-described specimens was HMS/1908 graphite epoxy plate with an isotropic layup. Again, in the absolute sense the experimental shear strength is quite adequate for the gimbal design.

Bond Shear Rigidity Tests

In view of the critical nature of the rigidity of bonded joints in the gimbal design, a special test was devised to determine whether a structural member composed of parts bonded together can approach the rigidity of a unitary member. The test specimen shown in Figure 7 was rigidly clamped in a vise-like fixture of very high mass and rigidity such that the specimen experienced vibration as a near-ideal cantilever beam when excited at its free end.

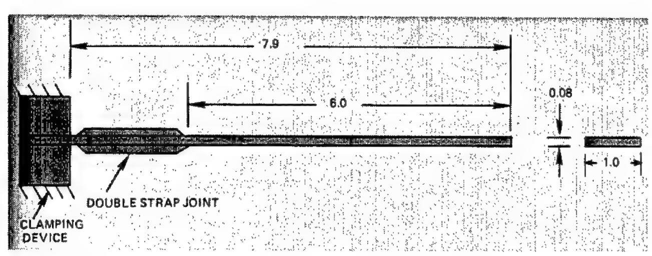


Figure 7

Using the expression for the first vibration mode of an end-fixed cantilever (after Hartog) and solving for Young's modulus E, the resulting expression is:

$$E = \frac{.4\ \pi f_n^2 \mu_1 \ell^4}{a_n^2 I}$$

f_n = the resonant frequency, Hz
μ_1 = mass per unit length of the beam, lb-sec^2/in.^{2}
ℓ = length of the beam, in.
I = moment of inertia of the beam section, in.^{4}
a_n = a constant (for the lowest frequency, the fundamental, a_n = 3.52)

For fn = 92.48 Hz, material density = 0.056 lb/in.^{3} and ℓ = 7.9 in. (the total length of the specimen including the double strap joint), the value of E calculated from the formula is 28.87 x 10^{+6} psi, which is much higher than a unitary structure of 0.08 in thickness should be. For ℓ = 6.0 (the length of the specimen outboard of the double strap joint) the calculated value of E is 9.607 x 10^{+6} psi.

Since the material is HMS/1908 graphite epoxy with isotropic layup from the same batch that was tested at the Westinghouse R&D Center, it is known that the actual E for a unitary specimen is very nearly 9.7 x 10^{+6} psi. It is concluded then that the vibration specimen of Figure 7 acts as if it were fixed at the beginning of the double strap joint. From this it can be inferred that the shear modulus of the FM 73 does not adversely affect fixity of members bonded as in Figure 7.

The question of the shear rigidity of the FM 73 adhesive, which has a cured film thickness of approximately 0.005 in. was also addressed in the tests. In the three point bending test, a double layer bonded sample did not develop as high a value of measured E as the unitary sample. This, presumably, is due to the shearing compliance of the 0.005 in. layer of FM 73, which in this case is located in a zone of very high shear. The loss of rigidity is not pronounced and the actual gimbal design will be more nearly represented by the specimen shown in Figure 7, which showed no loss of rigidity due to bonding.

Tooling Development

The in-house tooling effort was directed toward methods of fabricating the rectangular tubes. Filament winding is not appropriate due to the shallow angle (25 deg) with respect to the mandrel. After curing, a special collar and an arbor press were used to remove the parts. As mentioned earlier, the outside surface was machined to the final dimension.

Work was also conducted using external forms to eliminate the need for machining. A tool of this nature is shown in Figure 8. The part is fabricated by winding the prepreg tape on the expandable mandrel. The mandrel is then inserted into the external mold, expanded, and cured. To remove the part, the external mold is disassembled.

Additional tooling is being built to fabricate specific gimbal parts.

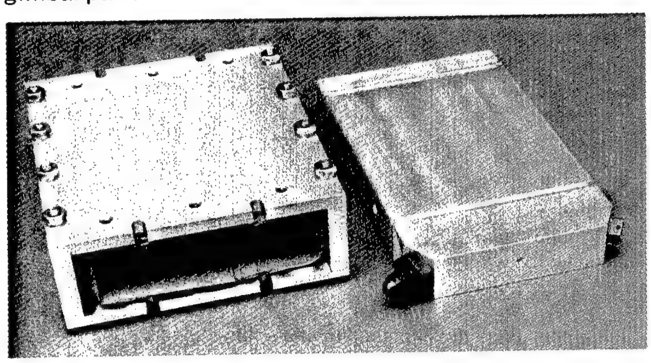


Figure 8

In a Nut Shell

Continuing studies indicate that the outer azimuth gimbal can be satisfactorily designed to use advanced composite materials. Detailed structural calculations and tests of material properties confirm that a weight saving is possible compared to the aluminum version. The analysis shows that the rigidity necessary for high resonant frequencies of the structure can be achieved with the weight-reduced structure, while structural damping will be considerably improved. The critically important transition structure between the torsion boxes and the innermost bearing support ring has been developed in the form of a circular box section which ties to the torsion boxes with double strap joints.

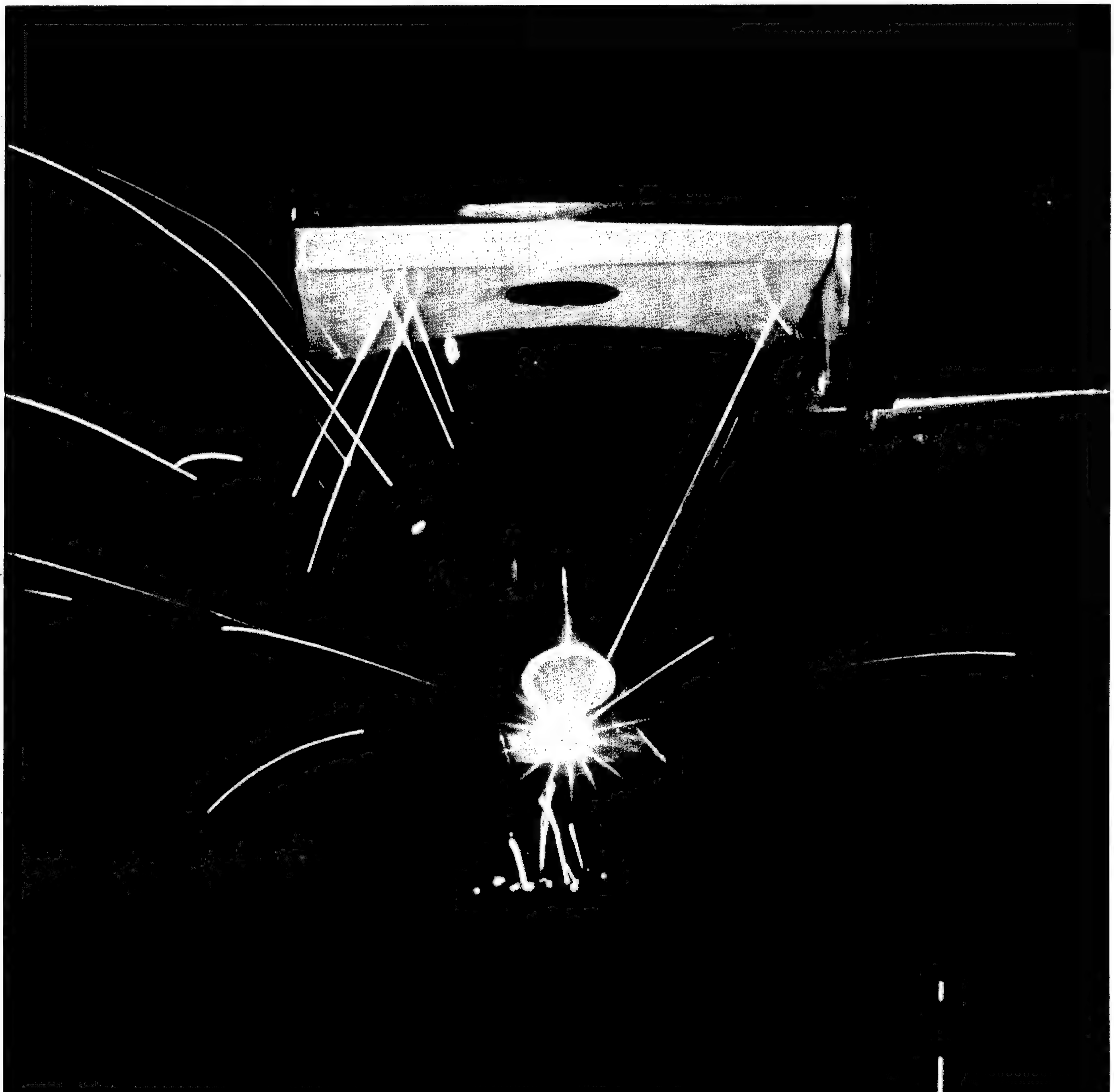
Tested techniques are now in hand for construction of boxes and plates, for metal insert fabrication and installation, and for composite-to-composite bonding. Experiments involving alignment of subunits during bonding as well as tests of the strength of the bond between the composite plates and the titanium inner ring are scheduled for the near future. When these are completed, all the techniques necessary for fabrication of the gimbal will be available.

US Army

ManTech Journal

Meeting the Challenge

Volume 6/Number 4/1981



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Contents

1 **Comments by the Editor**

3 **Guest Editorial: Attaining Proper Balance in Technology Transfer**

6 **Army's 1st IPI Program Begun — Blisk Impeller Followup**

15 **Lasers, Epoxy, Microprocessors Set New Standard**

21 **Brief Status Report**

28 **High Strength Torsion Bars Better Protected**

33 **G.E.'s ManTech Training Program**

38 **Tech Program Stresses Practical Skills**

41 **Automated Reporting Makes Workload Easier**

44 **Transcalent Transistor Dissipates Heat Faster**

46 **Antenna Design Simplified**

Inside Back Cover — Upcoming Events

ABOUT THE COVER:

Full penetration welding of stainless steel is being accomplished using a 5000 watt CO2 laser power source at Battelle's Columbus Laboratories. Evident here is a wealth of optical information about the quality of the weld being produced, information that is being used to develop in-process welding inspection techniques to establish new standards of reliability. For further information, contact Mr. Stan Ream, (614) 424-5663. (Photo by Battelle Photographer Janet Adams.)

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Comments by the Editor

RAYMOND L. FARROW

This issue of the U.S. Army ManTech Journal marks the end of our fifth full year of publication, a period during which there has been increasing emphasis placed on the Department of Defense's efforts to keep escalating costs in check through improved manufacturing technology. The coming year already has seen a marked expansion in planning for the mantech area. Within the next five year period, we will see a doubling of the MM&T program in the U.S. Army if the most recent recommendations from the Pentagon are accepted by the administration. The Air Force and the Navy also plan for their mantech programs to be sharply increased as the nation strives to meet the challenge of adversaries and at the same time maintain an armaments effort in balance with our economy. There is no doubt that the savings brought about by these mantech programs makes our military efforts much more compatible with the economic resources available to the nation. In fact, many believe therein lies our only chance to attain our armament goals and not seriously damage our economic resource base.

The guest editorial in this issue of the Journal points up one of the important issues of our time—namely, the limits to which we can go without hurting ourselves in the dissemination of information about these new manufacturing technologies. Everyone intimately associated with these mantech programs will agree that information transfer is extremely important and often imperative in order to maintain a steady rate of progress at the many widely dispersed offices and laboratories working on similar manufacturing problems. But the critic of this broad dissemination of newly acquired knowledge may say that we are "giving our know-how away" to foreign nations that do not have to expend the vast amounts of money and engineering time to attain the same level of technical capability. The author of the guest editorial on Page 3, Mr. George Schuck of the DARCOM Directorate of Manufacturing Technology, presents a thoughtful summation of the many factors pertaining to this issue. Mr Schuck is a longtime participant in the Army's mantech programs and has been the DARCOM representative at meetings of the Advisory Board of the U.S. Army ManTech Journal. He is conversant with all aspects of the Army's MM&T effort and is well qualified to address the issue of technology transfer.

Our editorial staff is most pleased to present an article on the Army's first official Industrial Productivity Improvement (IPI) program culminating several years of developmental work by the Aviation Research and Development Command and the Troop Support and Material Readiness Command. This multimillion dollar contract with Avco Lycoming marks the Army's first formal program under the new thrust toward cooperative implementation of new manufacturing technologies between the Army and its contractors. We expect to see many more such programs in the years ahead as the results of our MM&T projects are put into practice in the military production base. Mr. Art Goldberger, the TSARCOM engineer on the project during its developmental years,

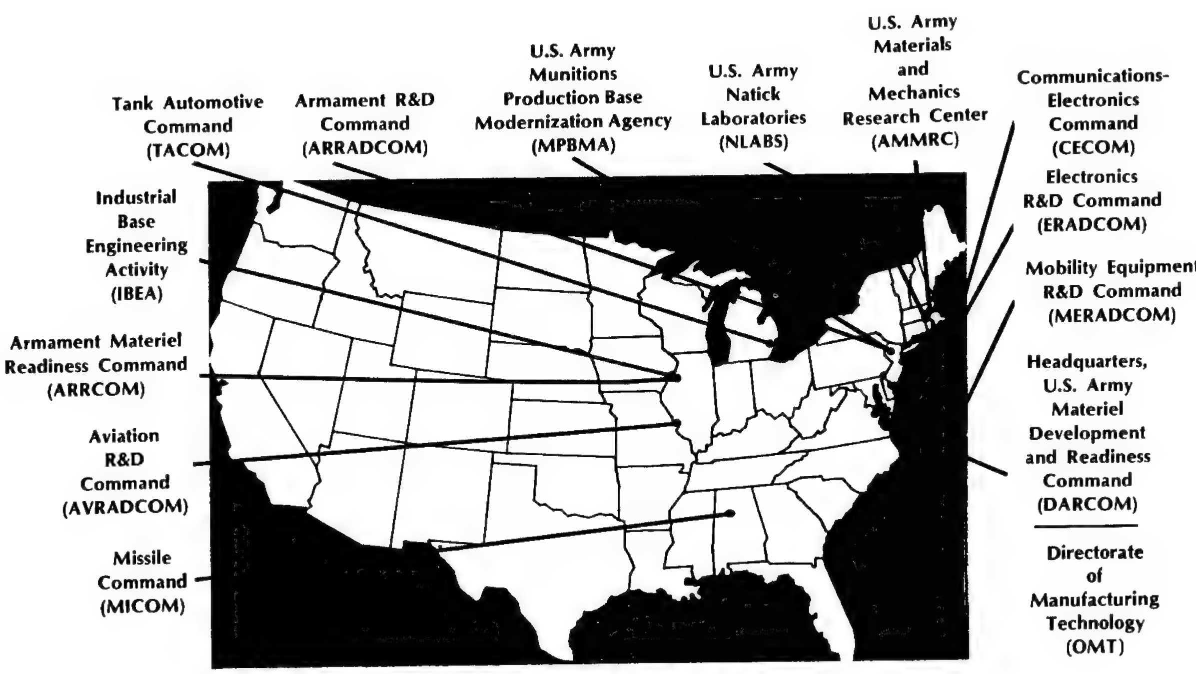
served in a pioneering role as the Army determined a supplier that could meet the stringent specifications and established a feasible plan of implementation. The effort is being carried on by his supervisor on the project, Mr. Jim Corwin of TSARCOM, who continues to oversee the progress of the program.

Another article in this issue that should find a wide audience is the one on development of a new process for terminating flexible printed wiring to connectors. This is a followup article to a previous one in the last issue of the Journal by the same engineer, Mr. Gordon Little of MICOM. The cost reductions attainable through the implementation of this new technology are truly outstanding and are typical of those often resulting from the Missile Command's programs, which are in the very forefront of new technology.

A project of the U.S. Army Tank Command is highlighted in the article on "High Strength Torsion Bars" which illustrates how a practical solution to a longtime problem of corrosion was achieved. Though there always are many different ways to solve any problem, generally one solution that presents itself stands out from the rest, and such is the case with this TACOM mantech project which uses a plastic coating for a more effective, longer lasting protective coating.

As in the past three issues of this year's Army ManTech Journal, we offer a pair of articles on special programs for the training of engineers and/or technicians who plan a career in manufacturing. The two articles in this issue describe the programs being carried out at Lynn, Massachusetts by General Electric for its Aircraft Engine Group employees and the four year B.S. program at Ogden, Utah conducted by Weber State College to train Manufacturing Engineering Technologists. Both are very practical, hands-on curricula attuned to the development of manufacturing personnel who can understand and operate the new technologies being developed around the world. Both programs were outlined at the 1980 MTAG meeting in Orlando. The company and the school should be commended for their sage approach to provide production personnel who can implement the vast array of new techniques being developed.

DARCOM Manufacturing Methods and Technology Community



Weighing Relative Needs

Attaining Proper Balance in Technology Transfer

GEORGE SCHUCK is a General Engineer assigned to the Directorate of Manufacturing Technology, U.S. Army Materiel Development and Readiness Command (DARCOM), Alexandria, Va. He is responsible for management of the Aircraft and Missile Manufacturing Technology appropriations at DARCOM and also serves as the Command's liaison with the Technical Consultants of the U.S. Army ManTech Journal.

In recent testimony before a Senate Foreign Relations Subcommittee on international economic policy, officials from the Commerce and State Departments indicated that the Administration is seeking to tighten controls on trade and technology transfer between the United States and Soviet bloc countries. Myer Rashish, Under Secretary of State for Economic Affairs, said the intent is not to stop trade, but merely to manage trade carefully in order to protect U.S. defense and national security interests. This marks a departure from the trends established by the previous administration and brings the overall question of technology transfer back into the spotlight. This has been an important issue since 1972, when a national program to stimulate transfer of technology from federal research and development programs was launched. It is a particularly important topic in relation to defense programs.

Much of the technology developed in the course of defense related research, particularly manufacturing technology, has a much broader potential application to other industrial products. Indeed, one of the purposes of the ManTech Journal is to help disseminate new technology and transfer it to commercial production. The possible impacts of such technology transfer on social and economic problems, both here and abroad, are enormous.

However, technology transfer also carries with it some strong security implications. Many questions arise in this regard. To what extent do we compromise our defense systems when we disseminate technology derived from their development while closely guarding the systems themselves? Do we transfer only products, through trade, or also the manufacturing and design technologies behind these products? Once technology is transferred from military to domestic civilian production, to what extent can we control its transfer to foreign industry? Do we want to control that transfer? These, and others like them, are difficult questions but ones we must face. And even beyond security implications, there are questions of the impacts of technology transfer on our economy. Consider briefly, then, some of the pros and cons of technology transfer.

In 1972, the objective in seeking to stimulate technology transfer was to encourage application of advanced technologies for meeting pressing social and economic problems. Such application remains a major benefit as the world tries to meet the needs of developing areas. Technology transfer can help "industrializing" countries to strengthen their industrial base and participate more fully in world trade. Eventually, these countries might become technology exporters, themselves. Such development, while it may create added competition for well developed industrial nations, can also help them by creating export markets for capital goods.

From the U.s. standpoint, the flow of technology can be a two-way street. Foreign investment in the United States, while often decried, generally brings with it new technology, particularly in the areas of material and energy conservation which have long been stressed in Europe. Furthermore, technology transfer opens more options to both consumers and producers in this country. Thus, there are some real benefits that offer sound reasons for stressing technology transfer programs.

However, we must also consider the other side of the coin—there are negative factors, as well. The ability of the United States to compete in world markets is based largely on the advanced state of the technology in this country. Wholesale export of our hard-won technology can severely erode our market position, leading to loss of jobs and, eventually, less capital to invest in further technological development.

An equally important issue is the security risk involved in exporting technology. Obviously, we keep close reins on high technology defense systems, themselves; this is not the problem. But much of our current technology is equally applicable to defense and nondefense systems. Neglecting for the moment any question of direct trade with the Soviets, we must realize that our allies are much more permissive in their dealings with Soviet bloc countries, simply because they are much more dependent on foreign trade. How can we be sure that transfer of technology on consumer goods, even to allied nations, will not ultimately contribute to an enhanced Soviet military posture? These products, though perfectly innocent themselves, may provide a critical manufacturing capability that supports strategic products. Or the product may have a significant military end use—microprocessors, for example, which can be applied equally well to hand-held games, machine tool control for improved productivity of commercial or military products, or weapons guidance systems. And even if we are exporting only products, does this potentially include the know-how to build that product? When we consider direct trade with the Soviets or their allies, all these issues become even more critical.

Considering both the pros and cons of the technology transfer issue, one would have to be very narrow in one's thinking to advocate that this country try to isolate itself technologically—probably an impossibility in any case. On the other hand, a laissez-faire approach to technology transfer would seem equally inde-

fensible. In the national interest, there must be some control of our technology in order to maintain both our defense posture and economic strength. This means careful consideration of the possible military implications of products and technologies before they are exported, as well as consideration of who they are going to and how they might be developed once released. It may mean an emphasis on the sale of products, minimizing export of the technologies producing them. It should mean extracting a fair price for our technology, both in dollars and in designating what technologies we want to import in exchange for those we export.

Judging from the Congressional testimony mentioned earlier, the current administration is well aware of this need and is taking an approach to control of trade with the Soviet bloc that seems to have the necessary moderation, in recognizing both sides of the issue. According to testimony by Lawrence J. Brady, assistant secretary of Commerce for Trade Administration, inadequate control of East-West trade in the past has led to higher U.S. defense costs. However, the administration realizes that the United States cannot, by itself, seriously limit Soviet access to our technology—export controls are effective only when exercised collectively by the Western nations. Thus, a part of the approach to control is a rejuvenation of CoCom, a coordinating committee to superintend Western trade in strategic goods comprised of all NATO members except Iceland (and including Japan).

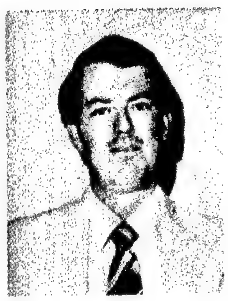
According to Rashish's testimony, the administration seeks to improve U.S. "ability to deny the Soviet Union equipment and technology to further its military objectives while allowing us to broaden certain economic ties that will permit us to exercise greater leverage and influence on Soviet behavior." He also said, "If the Soviets act responsibly and with restraint in the international arena, we are prepared to continue to expand our trade in non-strategic areas on the basis of mutual advantage. We are not prepared to forswear use of . . . controls as part of an overall response to future Soviet agressive action."

In a July conference in Ottawa, CoCom agreed to hold a high-level meeting to discuss means of improving multilateral controls on technology transfer. Brady testified that the United States has had no means to monitor and regulate trade with the Soviet Union, nor to integrate our trade policy with our foreign policy and defense doctrine. Rejuvenation of CoCom should help in these areas. Through this body, the United States and its allies hope to expand enforcement efforts on control of militarily useful exports and to attune licensing procedures. Furthermore, the Administration has enlarged the Compliance Division of the Commerce Department's Office of Export Administration in order to strengthen enforcement.

Such steps are necessary if we are to achieve a proper balance in the transfer of our continually advancing technology—weighing the need to disseminate technology that can solve world, social, and economic problems against the need to protect our own security and economic posture.

Factory of the Future Under Way

Army's 1st IPI Program Begun – Blisk Impeller Followup



ARTHUR E. GOLDBERGER recently joined the manufacturing engineering staff of McDonnell-Douglas Corporation as Manufacturing Systems Engineer after working the past six years for the U.S. Army, first as an Industrial Engineer and then as Project Engineer of various production base support efforts for the Troop Support and Aviation Material Readiness Command. During the past four and one half years he has headed up the Command's project implementing new manufacturing techniques and installing new machine tools for manufacturing blisk/impellers for the T700 turbine engine. In addition, he was heavily engaged with the planning and initiation of the Army's first IPI program. He spent the first year and one half of his career with the Army with the DARCOM Intern Training Center at Red River Army Depot studying product/production/design engineering. He received his M.E. in Industrial Engineering from Texas A.&M. in 1977 after taking his B.S. in Systems Engineering at the University of Arizona in 1974. At Texas A.&M. he performed special engineering work on NC systems and in numerical modeling. He is a member of IEEE and AIIE, and he is a Registered Professional Engineer. He also is a member of Theta Tau Professional Engineering Fraternity and Alpha Pi Mu Honorary Industrial Engineering Fraternity.

NOTE: This manufacturing technology implementation that is being carried out by Avco Lycoming is being funded by the U.S. Army Troop Support and Materiel Readiness Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The TSARCOM Point of Contact is Mr. Jim Corwin, (314) 263-2220.

Reduce fuel consumption 25-30 percent; reduce weight 40 percent; improve operating life; increase durability; and simplify maintenance via a more rugged design with fewer parts—and do it at low cost, but with exceptional quality. Those were the guidelines established in the mid-60's when the Army initiated studies on an advanced engine design for a new transport helicopter.

In early 1972, the Army selected General Electric Co. from among bidders to meet this challenge. And meet it they did, with the T700 engine which G.E. continues to produce at its Hookset, N.H. plant for the Hughes AAH (Advanced Attack Helicopter), the Sikorsky Black Hawk (formerly UTTAS), and the Navy's LAMPS (Light Airborne Multipurpose System). Through the use of a state of the art direct numerical control system, G.E. developed an automated process for the manufacture of blisks (an integrated blade and disk) and impellers for helicopter engine compressors. Design of a simplified engine using drastically fewer parts—along with performance of all machining operations in the blisk fabrication process at a single location—provided huge potential savings.

Now, with the signing of a multimillion dollar production contract between the U.S. Army Troop Support and Aviation Material Readiness Command (TSARCOM) and Avco Lycoming, the Army is taking another major productivity improvement step toward the manufacture of the AGT 1500 turbine engine for the M1 tank and the Avco T55 and T53 turbine engines for the Boeing Vertol CH47 cargo helicopter, the Bell UH-1 Huey, and also the Bell AH-1 Cobra. These engines will be built in the Stratford Army Engine Plant at Stratford, Connecticut by Avco Lycoming.

How did this program get from a "wish list" to production? By the development of new designs, by the use of new technology; and by the initiation of a new Army program—Industrial Productivity Improvement (IPI).

Near the completion of the blisk/impeller manufacturing project, the tools for greater efficiency at other Army turbine engine manufacturers' locations were defined by TSARCOM for the Army's first industrial productivity improvement (IPI) program. Through the implementation of an IPI program with top-down integrated design and planning at the Stratford Army Engine Plant, the Army and Avco Lycoming are working toward a complete restructuring of all echelons of organization, along with complete reequipping of the plant and production lines. These procedures will replace labor intensive functions with automated, carefully programmed production controls. A totally comprehensive approach, the new project will consider every facet of the plant's operation and management.

IPI Program—A First for the Army

The multimillion dollar contract with Avco Lycoming is a first for the Army, $1.7 million of which covers the initial phase of a unique Industrial Productivity Improvement program. This program takes dead aim on the contention of many experts that the productivity of American industry is in decline due to the obsolescence of our manufacturing plants and technologies; that decline purportedly not only has a negative effect on the economy and our ability to compete in world markets but also jeopardizes our ability to maintain a strong national defense.

Under the IPI program, an investment partnership is formed between the Government and the private sector through which industrial plants may be modernized and advanced manufacturing technologies implemented. For example, the Army Stratford plant where the new engines will be produced was built in the 1950's. It features much new technology and equipment, but essentially represents a case of "new wine, old bottle". The objective of this IPI program is to reduce the unit cost of gas turbine engines through improved productivity, the result of advanced manufacturing methods and technology.

IPI will analyze every facet of the Stratford plant, including subcontractor activities, and will focus on productivity, improved delivery, cost savings, and plant modernization. Both manufacturing and business systems will be evaluated. These include manufacturing methods and equipment, production controls and processes, quality control equipment, material handling and in-process storage facilities, organizational structure, inventory systems, and the use of computer integrated manufacturing.

The program involves three phases:

1. Definition of current practices and preliminary "zeroing in" on improvement opportunities

2. Specific identification and development of improvement opportunities

3. Formulation of plans and implementation.

The initial phase of the program covers seven months; halfway through this period, both Avco Lycoming and the Army must agree on a plan for the second phase, a $7.5 million, 18 month portion of the overall six year effort.

If all goes as planned, the Army Stratford plant will be transformed over that period of time into a "blue ribbon", advanced technology manufacturing facility—truly a plant of the future.

Past Experience Drawn Upon

Avco Lycoming is forging ahead with the appointment of several executives to direct work on this program. The firm also has engaged the services of Booz Allen & Hamilton as primary consultant. Booz Allen has experience highly relevant to this program, since they also worked on the U.S. Air Force version of IPI known as "TechMod". It should be noted that IPI is definitely not a copy of the Air Force program—while both have similar goals, their methods of supplying funds and incentives differ markedly. Some capital equipment will be owned by the contractor, and some ownership will be retained by the Army.

During the first month's reporting period the following was accomplished: (1) formulation of a detailed program master plan; (2) development of the systematic approach for cost/savings estimating; (3) establishment of a data collection plan.

The Strategic Master Plan (Figure 1) shows the schedule for the three phases of the program. The key events during Phase I are the formulation of Phase II technical and business plans, the development of the Phase II statement of work, preparation of the Phase II proposal, and documentation of Phase I results in the final report. The Phase II work statement was jointly developed by AVCO and the Army and was scheduled for delivery by the end of January, 1982.

The proposed management structure is shown in Figure 2. The approach for estimating costs/savings involves three steps: (1) develop cost baseline, (2) estimate cost savings, and (3) perform financial analysis. An overview of the approach includes the need to develop a computer program to perform financial analysis. The data collection plan includes:

- Definition of specific requirements for IPI program analysis
- Development of a data source matrix identifying primary and secondary sources for required information and a directory of AVCO personnel to be contacted
- Procedures for logging, tracking, filing, and summarizing data.

New Design = More Performance + Fewer Parts

What preceded the Army's IPI effort with Avco Lycoming? What proved that major productivity gains and cost reductions could be achieved by joint Government and contractor engineering efforts? As was stated earlier, the Army want to improve turbine reliability, maintainability, and manufacturing efficiency. General Electric was selected to develop an entirely new concept of engineering design to achieve these goals.

It was clear that the new criteria established by the Army called for a simpler, more rugged engine which would be capable of operating at higher pressures and temperatures than the one currently in use—the GE T58. Although the focus on simplification was applied to the entire engine design, particularly rewarding results were achieved in the compressor section.

The T58 compressor produced an 8:1 pressure ratio and consisted of 1400 parts—clearly not enough pressure and too many parts to meet the new demands. In addition, it was costly to produce and difficult to maintain.

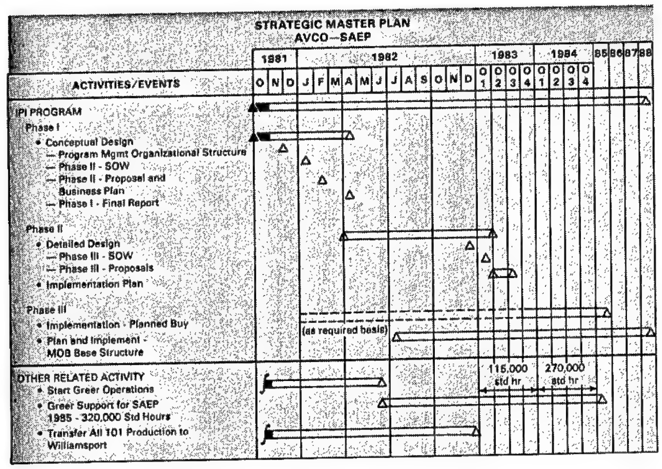


Figure 1

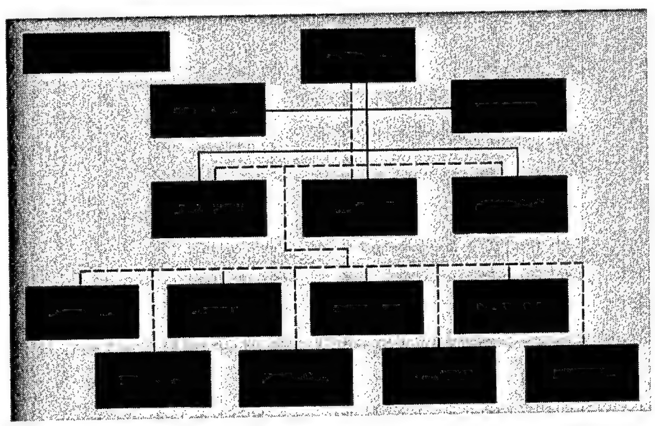
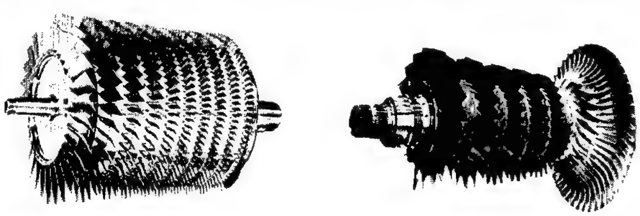


Figure 2

In their design approach of the early 70's, General Electric engineers realized simplification and strength would pay dividends in this compressor section and began their design work with this in mind. A key to this new design is the blisk—an integrated blade and disk. The use of blisks makes a huge savings in number of parts possible.

The new GE T700 turboshaft engine (Figure 3) is a major advance in gas turbine design. It generates 1500 hp from a 25 inch diameter package that is 46 inches long and weighs only 415 pounds. The T700 burns 25-30 percent less fuel, weighs 40 percent less, and requires considerably less maintenance than did previous helicopter engines. It produces a 15:1 pressure ratio with five axial stages and a single centrifugal stage. The 130 blades of its five axial stages are machined integrally on four blisks, and the completely assembled compressor contains only 352 parts (Figure 4). Each of the blisks forms a drum type of structure which is secured by mating surfaces and a tie-bolt to a single stage centrifugal impeller (Figure 5).



T58

- 10 Axial Stages Pressure Ratio≈8:1
- Individual Rotor Airfoils 634
- Stator Airfoils 752
- Individual Blade-Locking Screws
- Machined AM355 Casing
- Variable Stators 4 Stages
- Total Parts 1,386

T700

- 5 Axial Stages, 1 Centrifugal Pressure Ratio +15:1
- Rotor Airfoils 130 9-part "Blisk" Design
- Stator Airfoils 202
- No Blade-Locking
- Cast Titanium Casing
- Variable Stators 3 Stages
- Total Parts 352

Figure 3

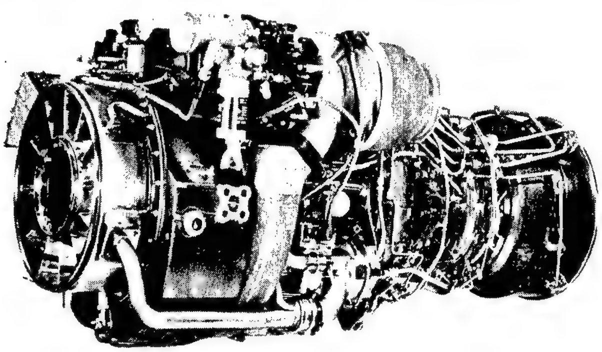


Figure 4

Blade Geometry A Challenge

Blisk geometry is enormously complex. The Stage blisk, for example, is 7.7 inches in diameter and consists ol 20 identical blades that radiate from a hub; the outer aerodynamic surface of this hub is called the "platform". The airfoil, or cross sectional shape of the blade, is a precisely defined curve that is concave on one surface and

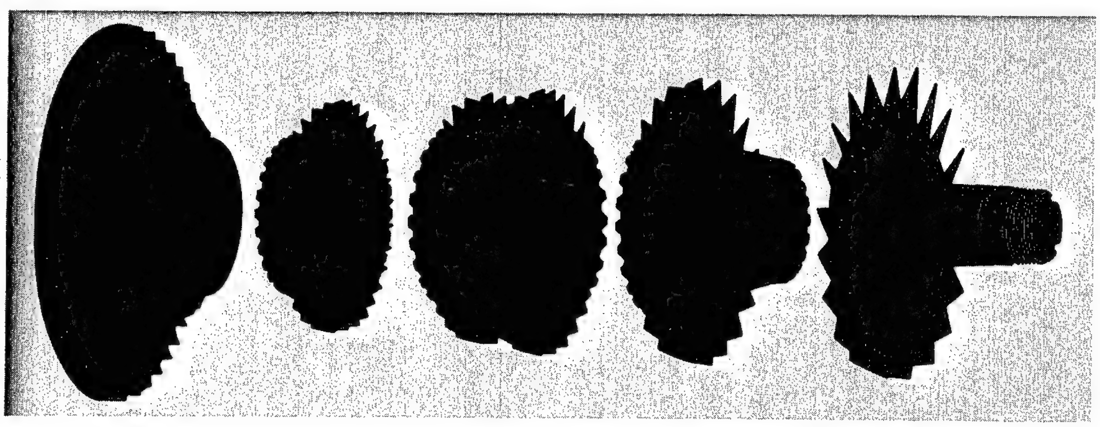


Figure 5

convex on the other. Thickness of the airfoil tapers from its base intersection with the platform and thins out toward the tip. The blade is twisted to follow a helical aerodynamic path in operation. What results is a pair of surfaces of compound curvature with overhanging areas (due to twist) that cannot be generated by a straight line and that present potential cutter-shank interference problems at the blade tip while machining is being done lower down.

The platform isn't exactly a simple shape, either. It also is an aerodynamic shape approximated by blending nine cones in the length of the airflow path, which is a bit more than 1.25 inches on the first stage blisk.

The final geometric challenge is to blend these two complex surfaces with a root fillet, the radius of which must be perfectly tangent to both airfoil and platform.

Conventional Methods Costly and Inefficient

Using conventional machining methods, blisk forgings are turned to a rectilinear shape and inspected ultrasonically prior to semifinish turning of the airfoil area. The blades then are rough milled on a tracer miller and contour milled with a hand pantograph-assisted milling machine one piece at a time. The proper shape and dimensions are obtained through in-process inspection of the airfoil using a manual tracing stylus/comparator.

Finish turning, drilling, and grinding are done on conventional equipment. The required airfoil surface finish is obtained by hand polishing, while blade leading edge and trailing edge profiles are hand filed to the proper contour with the control aid of optical devices.

The impeller follows the same rough and finish machining processes, except that rough milling is replaced by electro-discharge machining and coating is not required.

The complete conventional machining cycle involves operations at five widely separated geographic locations. Parts are inspected at the source prior to delivery for coating, curvic grinding, and balancing. There is a definite risk of damaged or lost parts, and shipping charges increase part costs.

MM&T Program Required

To meet the Army requirements, the compressor had to be producible at low cost and in high volume with repeatable precision. And this was dependent on development of the ability to produce blisk and impeller airfoils with new processes and equipment. Therefore, new machining, finishing, and quality control processes were needed. These developments became the focal point of a high priority Manufacturing, Methods, and Technology (MM&T) program. The objectives of the program were to develop a manufacturing system for producing the airfoils as integral features of blisks and impellers that comprise the rotor of a six stage compressor for the T700 which would:

- Produce airfoils to stringent design requirements, including large twist angles, close spacing, thickness within +4 to -3 mils, contour to ±1.5 mils, surface rougnness within 32 microinches AA
- Eliminate major dependence on manual skill and high labor requirements which characterized established previously used processes
- Meet specifically defined manufacturing costs
- Make it possible to start production within a three year period and to rapidly increase the production rate
- Improve the repeatability of all processes to ensure quality in volume production
- Achieve engine performance equal to performance attained by established previously used processes.

The new approach introduced a complete manufacturing center which utilized computer directed numerical control equipment. With everything done at one location and the operations automated, efficiency could be vastly improved.

Acquiring Machinery No Panacea

In the original quest for a machine tool supplier to furnish the equipment that would be capable of doing the job, TSARCOM soon faced a serious obstacle. Of nine firms receiving RFP's, only three responded, with some of those most highly qualified declining to submit bids due to total commitment of their resources over a several year period. Also, the potential of the Army production was not at that time great enough to warrant a high private capital outlay for equipment that would be required. As a result, many of the most capable machine tool suppliers in the United States did not make their facilities and skills available for this particular defense production program.

Of the three firms that entered bids, one domestic firm eventually succeeded in achieving a machine that was capable of turning one axis of the required five axis machining within specified tolerances, and one other domestic firm has yet to provide a machine that would handle any one of the axes required. The machines that are being emplaced in the production line by necessity are of European design and manufacture as the only machine tool currently capable of handling all five axes of the machining requirements within specified tolerances. Special permits from the Commerce Department have been required to allow the Army to procure these machine tools in order to meet production schedules over the next few years.

Specifications Most Stringent

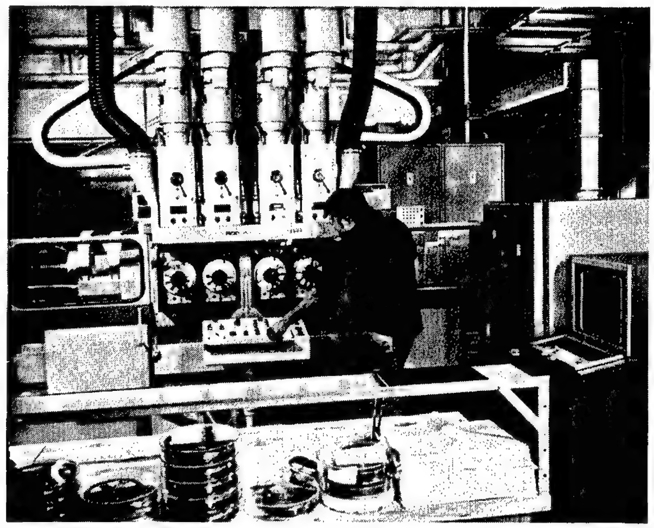
Briefly, blisk forgings are machinined to within 0.125 inch minimum envelope of their rectilinear confiuguration on a heavy duty numerical control dual spindle verticle turret lathe. Ultrasonic and magnaflux inspections precede finish turning on a numerically controlled slant bed turret lathe. A special grinder fitted with index plates performs slotting operations. Splines for Stage 1 are cut by a precision gear shaper.

Airfoils are formed from the solid disk on the newly developed four spindle numerically controlled milling machine using successive program tapes that control the rough and finish operations in proper sequence (Figure 6). The first pass roughs and finishes every other pocket (the space between two adjacent blades). These pockets are then filled with a matrix metal that melts at low temperature. This matrix provides maximum rigidity for the second pass during which the remaining pockets are machined. After this second pass, the matrix is removed and recycled.

Two closely related tasks were also pursued at the same time as the machining was developed. First, to obtain the required airfoil surface finish and contour, abrasive flow machining was developed. Second, special equipment had to be selected for inspection of the completed airfoil.

The New Process in Detail

Raw materials for the blisks and impellers come into the plant in the form of rough forgings. The blisks are made of AM355, a precipitation hardened stainless steel with 0.13% carbon, 15% chromium, 4% nickel, 2.5% molyb-



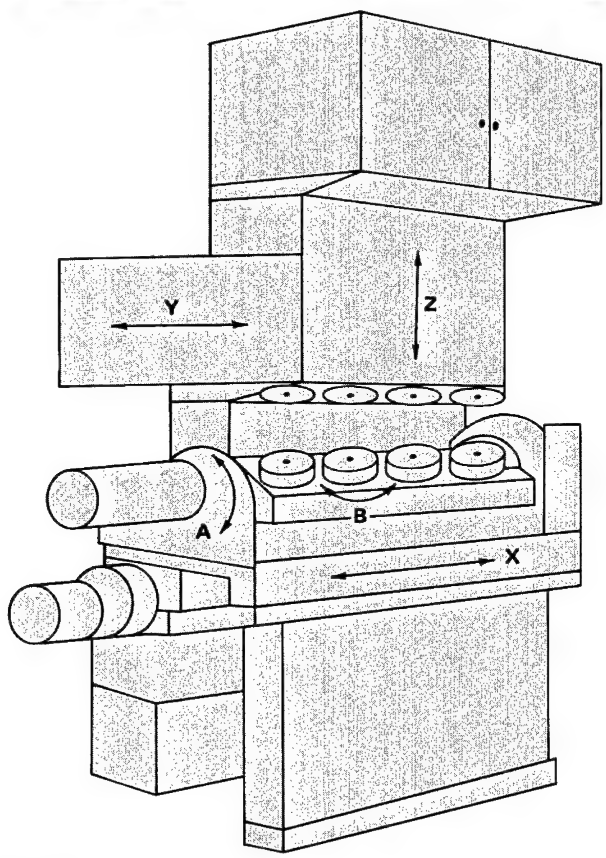


Figure 6

denum, and 1.1% managenese. Hardness is in the range of Rc 35-43, and the machinability rating of the alloy is 40. The impellers are of Inconel 718, a high temperature nickel base alloy with a hardness of Rc 38-47 and a machinability rating of 12.

The first machining operation is to preturn the forgings to a proper "ultrasonic envelope" consisting essentially of true cylindrical shapes with 0.100 inch of excess metal on all surfaces. This operation is performed on a New Britain twin spindle vertical chucker. Cermet cutting tools are used for the AM355 forgings, while ceramic ones are used for the Inconel forgings. The ultrasonic checkup of the soundness of the forgings is then performed, and the blanks then go to a P&W star turn chucker for finish turning. This consists largely of hub face and bore detals inside the platform diameter. Carbide tooling, including indexable drills and some special tools for contoured bores, is used in these operations.

A number of other machining operations are performed in the hub areas before blades or the "slots" between the blades are milled. These operations include drilling bolt hole circles (on four specially fixtured bench drills), generating Curvic couplings (the compressor's components are ultimately assembled with drawbolts, and the Curvics ensure alignment), spline cutting on the Stage 1 blisk (with a gear shaper), and some grinding operations.

Blade milling on the blisks and impellers is obviously the key element in manufacturing the compressor rotor, and as previously mentioned, it is the most unconventional operation involved. It is performed on nine four spindle five axis computer numerical controlled milling machines (Figure 6). The head of the machine carries four verticle spindles, each powered by a 10 hp dc motor which is capable of speeds up to 12,000 rpm. The head travels 8.86 inches vertically in the Z-axis and 17.72 inches horizontally (in and out) in the Y-axis. A table beneath the spindle provides X-axis travel of 11.81 inches. Maximum feedrate of each of these linear areas is 100 ipm. Mounted on this table is a full length trunnion (A-axis) that rotates from 10 degrees below the horizontal to 20 degrees beyond vertical (120 degrees total). The trunnion itself carries four rotary work stations (the B-axis, perpendicular to A), which provide continuous rotation capability for the workpiece fixtures.

With four identical workpieces fixtured, every other slot is milled—both rough and finish—in the first complete pass around the blisks. These slots then are filled with a low temperature melting alloy which has a zero thermal expansion, and a second complete pass is milled. The matrix metal, which stiffens the thin blades during machining, is subsequently melted out and recycled. The blisk then goes to the abrasive flow machining (AFM) station. There, the desired leading and trailing edge contours and surface finish of blades and platforms is performed.

Milling times run from 28 hours for four Stage 5 blisks with their relatively short blades to 125 hours for a machine load of dual Stage 3/4 blisks with their 56 blades each.

Impeller Machining to Improve

Machining and finishing of the Inconel impellers is essentially similar to that of the blisks, with two major exceptions. Because the impeller blades are much shorter and stiffer, they do not require reinforcement by the low melting matrix metal. And, because of their totally different geometry, the impellers require the full five axis capability of the milling machines. However, because of larger size, the relatively large number of blades (45), and the low machinability of the Inconel, milling an impeller takes longer: 525 hours at present for a machine load of four. This is one step which will be optimized as part of the IPI program.

All milling operations are done with solid carbide end mills of 1/8 to 3/8 inch diameter and with corner radii up to a full ball end configuration. In all, there are 11 different configurations. Typical speeds are about 2000 rpm for roughing with 5/16 inch end mills, 6000-8000 rpm for blade finishing with 5/16 inch ball nose cutters, and 10,000-12,000 rpm for platform finishing with 1/8 inch ball nose cutters. Downfeeds are typically 0.120 inch per pass roughing, with cuts staggered from one side of the slot to the other. For blade finishing, the downfeed is reduced to 0.025-0.35 inch per pass to reduce the scallop height between adjacent cutter paths. A flood of sulfochlorinated cutting oil is used in all milling operations.

Tool wear is such that it takes 196 cutters to mill a complete set of compressor rotor components: 96 for slot roughing, 80 for blade finishing, and 20 for platforms. Each cutter can be reground about ten times.

AFM

Abrasive flow machining (AFM) is a newly developed technique which is being used for final finishing on axial and radial flow airfoils. Engineers first tried electro-

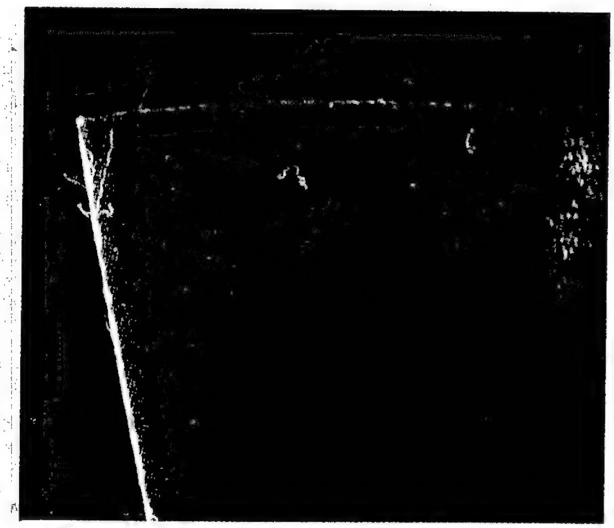


Figure 8

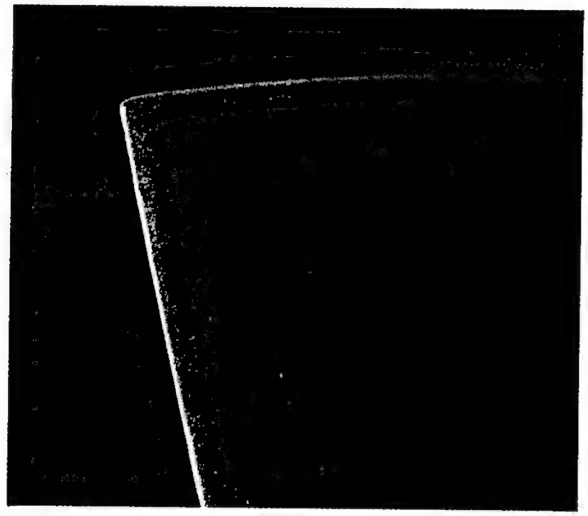


Figure 9

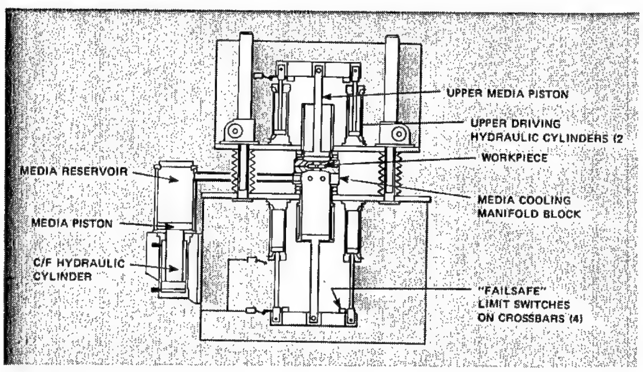


Figure 7

chemical and proven abrasive processes, but they did not meet the requirements. In this process, an abrasive solution is passed over the part to be finished. This required development of the right media viscosity, the right combination of abrasive particles, and the correct pressure/temperature conditions to flow the abrasive media between the airfoils, following the airflow path. Figure 7 shows the machine that was developed for this process; Figure 8 and 9 show a leading edge contour comparison before and after abrasive flow machining. A texture comparison is shown in Figure 10.

Advanced Quality Control

After blisks and impellers are complete, they must be closely inspected to make sure that they meet the design requirements. In addition, they are checked at each stage throughout their manufacture. Figure 11 shows a blisk airfoil measuring machine and Figure 12 shows an impeller measuring machine; these units are highly sophisticated. The last stop for blisks is a balancing station. There, the balancing machine outputs dynamic imbalance data directly to a minicomputer. The computer in turn

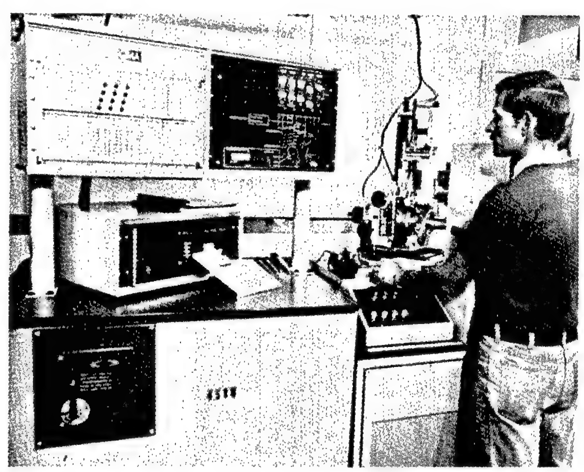


Figure 11

processes the data to generate a corrective machining program and transmits it to the computer numerical controlled Wells Index vertical mills. When the blisk is re-

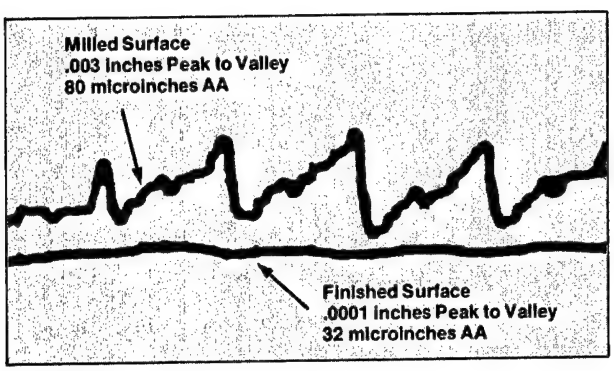


Figure 10

moved from the balancer and mounted on the mill table, the mill proceeds to remove the required amount of metal from the required location on the balancing land, which is a raised area of metal within the hub of the blisk that is left there for this purpose.

Blisk and IPI Future?

The future looks bright for the production of blisks and impellers under the manufacturing methods described here. This is especially true when you consider that these new methods and designs reduce the manufacturing cost

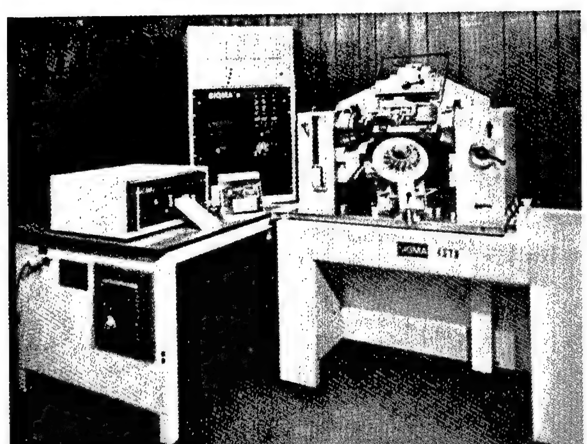


Figure 12

for an engine set by 60 percent and have been projected to save the entire program more than $60 million. In addition, this technology is well suited to other high volume, high precision, cost sensitive manufacturing programs.

What about the IPI program itself? AVCO and the Army are off to a good start and have made progress during the short time it has been in operation. Future reporting will be monitored to keep track of this newly formed partnership and their accomplishments.

Flexicon: A Live Wire

Lasers, Epoxy, Microprocessors Set New Standard

GORDON D. LITTLE is an Electronic Engineer in the Engineering Directorate of the U. S. Army Missile Command, where he currently is Project Manager on the Department of Defense's Electronics Computer Assisted Manufacturing (ECAM) program, a recently initiated effort similar to the Air Force ICAM project. This forerunner program is being steered by an MTAG working group comprised of the Subcommittees on Electronics and CAD/CAM. The first phase of this broad based program is scheduled for 18 months of duration. Prior to this assignment, Mr. Little conducted developmental work after joining MICOM in 1971 in automated testing, microelectronics, automated test equipment, and packaging and design of a digital automatic pilot. Prior to his work at MICOM, he spent 12 years with Westinghouse, Sperry, and AMF Corp. He received his B.S. in Electrical Engineering in 1958 from Auburn University and his M.S. in Electrical Engineering in 1971 from The University of Alabama at Huntsville. He is a member of the International Society for Hybrid Microelectronics and serves as Chairman of the MTAG Working Group on Components and Packaging, a part of the Electronics Subcommittee of MTAG.

Through the use of industrial laser technology, new high speed epoxy developments, and microprocessor controlled automation, processes for termination of Flexible Printed Wiring (FPW) to connectors have been developed which can result in 6 to 1 cost reduction of terminated systems with significantly improved system reliability and maintainability.

The Army sponsored project on Flexible Printed Circuits with Integral Molded Connectors (FLEXICON) was performed under contract with the U. S. Army Missile Command, Redstone Arsenal, Alabama. It concentrated on the improvement of FPW terminations for cable to cable, cable to printed wiring board, and cable to chassis applications. During the course of this program, several significant advances were made in termination processes as well as in automated facility configuration and operation. The final outcome can be simply summarized.

Ingrained Resistance Replaced

Flexible printed wiring and flat conductor cable (FCC) have been available for many years for use with military systems. Their primary advantages are a 30-50% basic cost reduction, a 70% weight reduction, an 80% volume reduction, repeatable electrical characteristics, substantial quality improvement, and improved aesthetics. They have held promise of significant benefit in electronic systems, particularly as interconnection wiring has become increasingly more complex with each passing year. There have been two major factors which have inhibited its greater use in military electronics. First, since it is a "printed" technology, wiring changes as defined for hand formed harnesses could not be performed, and design engineers who were accustomed to the freedom of frequent design change did not wish to become "trapped". Second, the available processes for termination to mil-qualifiable connectors, particularly for humid airborne environments, were expensive, difficult to control, and not cost effective. Even so, the cost benefits of using FPW over hand formed harnesses could be substantial for production quantity systems, not only from acquisition cost but from reduced quality control requirements and life cycle cost benefits of weight and volume savings.

In the past few years, the ingrained resistance has been replaced with substantial knowledge of benefits as design philosophies have changed. Digital systems with data bus configurations are well behaved with the repeatable, designable electrical characteristics of FPW and FCC. Dramatic increases in equipment density have forced many systems to use this cable style because space was no longer available for the round wire harnesses. And the trend to more production systems with less changes in

NOTE: This manufacturing technology project that was conducted by Westinghouse Electric Corporation was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Gordon Little, (205) 876-3604.

interconnection between subassemblies has led to a greater cost benefit. The only major hurdle remaining was the termination process/connector interface.

An Example — Round Wire Impractical

An example of the termination dilemma can be seen with the evolution of a new production electronic system at Westinghouse. When the program was conceptually developed in the early 1970's, it was determined that the modular interchangeable location of the separate subassemblies and the parallel data bus requirements could be best suited with the use of FCC. This was particularly beneficial because the lack of volume for wiring rendered the use of round wire impractical. In the initial four units, these cables were configured as shown in Figure 1. The connectors were three layer, 141 pin connectors with the FCC welded to the contact tails by resistance welding. The backs of each wafer were then slid onto the contact wafers and filled with epoxy. These connectors, designed to MIC-C-55544, were expensive, fragile, and difficult to assemble. Rework was virtually impossible.

With the shift of this program into production, this connector was replaced with a connector that was soldered (lower reliability) with a gang solder technique. Repairable, of adequate reliability, and infinitely more easy to assemble than the prototype units, this configuration still had two major deficiencies—cost and process control. Another termination technique used on this same program was the crimping of contacts through the insulation. The process control and reliability of these joints both have been in question. These difficulties had to be approached with deliberate thoroughness and resolved.

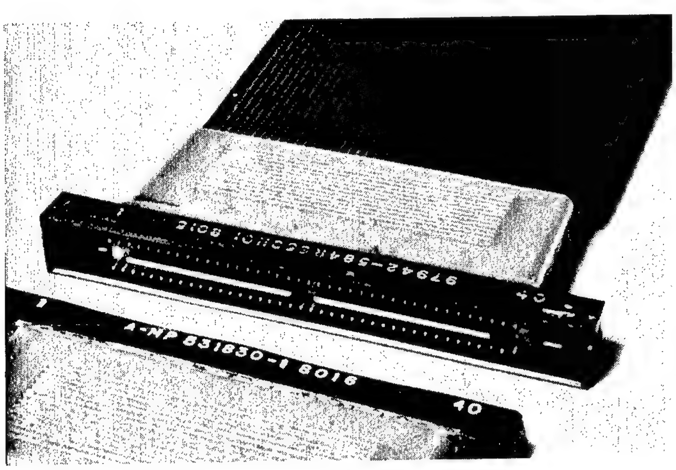


Figure 1

Five Step Program Defined

The principal requirement was the development and demonstration of a flexible printed wiring termination technique which was consistently low in cost and reliable in the military airborne environment. To accomplish this, three basic items were needed: (1) low cost connectors and FPW, (2) low cost reliable termination processes, and (3) a high degree of automation. To provide this, the program was organized to:

- Select connectors for demonstration.
- Select termination processes.
- Demonstrate the necessary techniques.
- Develop semiautomated process stations and operate them successfully.
- Define a fully automated facility which could terminate up to 500 assemblies per eight hour shift using the developed processes.

Connectors Selected

Flexible printed wiring is a planar technology—that is, all the conductors are in a single common insulation on a plane; therefore, connectors that lend themselves to the planar technology were selected. In this program, they were limited to two row connectors. Connectors of 50 mil pitch (that is, 50 thousandths of an inch center to center spacing on the contacts) and 100 mil pitch were both demonstrated in this program. The bulk of the program was worked with the 50 mil connectors. Dual row connectors with 40 contacts per row were primarily used.

Selection Technique and Results

The selction technique which is used for evaluation and selection of connectors and later extended into selection of the process was developed as an extension of a technique

used by the National Institutes of Health in the 1960's. A matrix of values was first established for the connectors that were under consideration establishing the relative score of the connectors one to another for each of several factors. The columns in this matrix were determined independently—that is, relative cost of connectors had no direct interaction at this point with any of the other columns in the matrix. In this way, the relative weighting of the seven factors for importance was separately determined. By post multiplying the factor matrix with the factor weighting which is shown on the right side of Figure 2, a value matrix which is weighted is realized with the sum of each row indicating the total value. This is shown in Figure 3. The algebraic matrix notation is [A] [B] + [C]. The way these matrixes were established, the lowest number indicated the best selection. These results indicate that the Amp mini-box connector should be considered first. A close second was the Hughes IBM connector. Two further considerations not shown in the evaluation were that the Amp mini-box connector already had met QPL of MIL-C-55302/117, 118, 119, 31 (with no interfacial seal), and that Burndy could be a second source for the Hughes connector. Both of these connectors selected have now been modeled with an interfacial seal.

Modifications To Connectors

Two basic modifications were necessary to both Amp and Hughes connectors to make them usable in the MIL airborne environment. The first involved the realignment of the contacts and contact tails so that instead of four rows of contact tails out the back of the connectors there were only two. The second modification required the addition of an interfacial seal. This was performed for low cost on a temporary basis in the Amp connector by laser drilling holes in a thin sheet of silicon material. In the Hughes connector, this was done by using a modified connector as a mold and pouring thin layers of the silicon rubber. In the cases of both connectors, the modifications for the contact tails and for the interfacial seals were considered to be of a temporary or prototype nature. Both must have some consideration in the form of slight design changes and proper tooling for production capability.

Variable Factors / Connectors	Relative cost of connector	Degree of tooling req'd	Mat'l/parts available	Current carry capacity	Adaptability to mold	Reliability	Process compatibility
BURNDY ML 80	4+	2	2	4	2	5	5
ITT MEB or MT	8	2	1	1	5	6	8
AMP Minibox	2	4	1	3	5	3	3
Hughes 1093212	4	2	2	4	2	5	5
$[A]_{ij}$	9-high 1-low	9-much 1-little	9-poor 1-good	9-poor 1-good	9-poor 1-good	9-poor 1-good	9-poor 1-good

Relative Weight	
Cost	.20
Tooling	.16
Available	.06
Current	.02
Moldable	.21
Reliable	.22
Proc. Comp.	.13
	1.00
$[B]_j$	

Figure 2

	Relative cost of connector	Degree of tooling req'd	Mat'l/parts available	Current carry capacity	Adaptability to mold	Reliability	Process compatibility	Totals	Rating
BURNDY ML 80	.8+	.32	.12	.08	.42	1.10	.65	3.49+	3
ITT	1.6	.32	.06	.02	1.05	1.32	1.04	5.41	4
AMP	.4	.64	.06	.06	1.05	.66	.39	3.26	1
Hughes	.8	.32	.12	.08	.42	1.10	.65	3.49	2

Figure 3

One further modification had to be demonstrated for these connectors. Since neither of the connectors had available jacking (mating) hardware the Amp connector was selected for a small development effort to design and demonstrate the availability of jacking hardware for this size connector. This has already been extended by Amp, Inc. to the point that there are now at least four different styles and sizes of jacking hardware available for the Amp minibox series of connectors.

The Amp connectors are also available for termination to printed wiring boards both at right angles (as with plated through holes) and straddle mount (as with surface mounted components).

Easily Tested Approach Needed

Conductor termination of flexible printed wiring to many sizes and varieties of connectors is possible. A technique which does not limit the process to only a few connectors was desired. Crimping systems, solder systems and parallel gap welding systems have been the major approaches taken to date. Each has serious drawbacks. What was needed was a high speed, reliable, easily tested approach which could be applied with ease to a large variety of planar connectors.

The evaluation of processes for the termination of flexible printed wiring to connectors as well as connectors to

printed wiring boards was conducted using the same technique as used for connectors. The process selected for the termination of the flexible printed wiring to connectors was the use of laser welding, and for the termination of connectors to printed wiring boards was wave solder for right angle termination connectors and laser welding or vapor phase reflow for the termination of connectors to printed wiring boards on surface mount. At this point, we would recommend the use of the vapor phase reflow since no further development work was done on the laser welding termination to printed wiring boards.

Laser Stripping

Insulation removal of organic coatings and insulations from the one to two mil thick copper wiring without damage to the conductors has always been a challenge. Present flexible printed wiring approaches include skiving (mechanical abrading) or using noninsulated areas. In skiving, mechanical action against the conductor is necessary, often resulting in scored, scratched and even broken conductors. In noninsulation, custom design of each circuit cover coat is required. Sometimes prepunching of the base insulation even before lamination of the copper foil is required.

The process developed for the removal of insulation from flexible printed wiring with no mechanical handling of the conductors is laser stripping using the 10.6 micron wavelength of the CO_2 laser. This technique allows the complete ablation of the insulation material with no thermal, mechanical or metallurgical deformation of the conductors of the flexible printed wiring. There is a wide range of laser power requirements and spot diameters over which this technique will work. Primarily, the use of 100 kilowatts per square inch power incident at the surface of the insulation has been found to be optimal. The polyimide insulation absorbs the laser energy, and rapidly and locally reaches ablation temperature, breaking down into its primary chemical constituents. These vapors can be easily vented away and/or filtered. We have found that the best approach is to only remove the insulation from one side of the cables. This completely opens the windows between the conductors but leaves insulation material on the backside of the conductor which significantly enhances the welding operation which follows. Cleaning of the flexible printed wiring after the laser ablation is easily accomplished with a solvent rinse accompanied with a very light brushing to remove any particulate which is left. Testing of circuits thus prepared with 25 mil spacing between the conductors showed that there was a 55 megohm resistance from conductor to conductor after the laser stripping (before cleaning) and that after cleaning the insulation resistance was on the order of 2 million megohms using 500 volt potential at one minute time duration.

Laser Welding

The laser welding of flexible printed wiring to connector contact tails has been performed using a Neodymium:YAG Laser operating at 1.06 micron wavelength. The process specification for laser welding to connectors is included as Appendix E of the report and further details are also contained in the technology introduction reports in Appendix I. In addition to these reports, one particular emphasis needs to be made in regard to the laser welding. This technique has a wide latitude of weld schedule providing a much higher reliability of finished product because the weld schedule is easy to maintain. This was done, however, on conductors that were a mil and one-half thick against contact tails that were eight to ten mils thick. In this approach when we hit with two pulses from the laser on each contact within a few milliseconds of each other, the first pulse tended to vapor gas the insulation, providing a much higher pressure of contact for excellent thermal transmission between the upper conductor and the lower contact tail when the second pulse hit. This provided an excellent weld. One of the prime reasons that the weld schedule is so large is because of the amount of thermal transfer that can occur into the eight to ten mil thick contact tail without having a loss or a vaporization of the metal or the copper on the surface. Welding using this approach to a thinner contact tail, say one mil or one and one-half mils, as in trying to weld flex cable to printed wiring boards, may require a much tighter and much more closely controlled weld schedule. This was not investigated within the confines of this program.

Several tests were conducted of welds made using this technique, from welds which were just barely complete to welds which had blown away 50% of the material of the conductor and the contact tail. In all cases, failure of the conductor occurred away from the weld area with no failure at the weld itself. Metallurgical examination of the welds showed excellent weld cross section with some gas trapping as a result of the rapid cooling. Remember that laser welding heats up only a very small amount of the material. There was a very high degree of consistency of

the welds; thus making visual inspection a very practical way of guaranteeing an excellent weld product.

Molding — Environmental Protection

For molding, a fast curing semiflexible, environmentally resistant material must be used. This material must be rigid enough to support the weld terminations yet flexible at the exit point of the cable to prevent circuit breakage when cables are flexed at the connector.

In each of these three areas, significant advancement has been made by this program in the development and demonstration of processes beneficial to the termination of flexible printed wiring to connectors.

The principal requirements for molding of this termination are two: one is to provide the strain relief so that there is no loading or flexing of the circuits at the weld interface; the second is to provide a shield against contamination and dirt and, particularly in the military airborne environment, against moisture. To select a molding compound which would meet all of these requirements was not easy. The majority of molding compounds which are rapid curing are also rigid in their cured state. When a molding compound is applied to flexible printed wiring, it tends to terminate at the wiring in a fine miniscus which leaves a sharp point of material against the flexible printed wiring. Thus, the material must be somewhat flexible or that miniscus acts as a knifepoint which will break the circuit in a few flexes when it bends right at the connector. Therefore, selection of a semiflexible compound which would support the welds, adhere well to the flexible printed wiring, particularly the organic polyimide material, and also be semiflexible at degrees of the cable was important.

One other item needed to be considered in the area of molding of the connectors for this program. Most connectors supplied from vendors today are manufactured by the use of a basic mold block of insulating material into which contacts are inserted. This leaves a gap of air or space around the contacts of the connectors. This space must be filled and sealed prior to the use of a molding compound or that molding compound will run through and fill up the cavities that the pins are in.

The molding operation with the Hydantoin epoxy, proved to be an excellent process with connectors of a thermoset epoxy such as the Diallyl Phthalate. A thermoplastic material such as Valox, though, did not work well with this process because it required too high a temperature. Therefore, another epoxy formulation—a fast curing Bisphenol Epoxy Compound RZ48-2—was developed for use with the thermoplastic connectors.

Semiautomated Processes

The three major processes established for the termination of flexible printed circuits with integral molded connectors were set up in semiautomated form for industry demonstrations and for the purpose of establishing cost information for the program. The molding operation was the simplest and required only a timer to operate the pneumatic control system for the molding. In both the laser insulation removal and the laser welding operations, an Aerotech controller was used. Most of the details of the semiautomated equipment are shown in a motion picture film which was prepared for the project. Much of the information learned from the semiautomated operations was applied to the fully automated facilities development program which will be discussed later in this report.

Environmental Evaluations

Throughout this program several evaluations and tests were conducted on materials and processes to verify that the approaches taken would be acceptable within the military airborne environment. The testing is broken down into basically three steps. The first step involved evaluation of the flexible printed wiring after laser insulation removal to verify that the particulate matter left did not short out the system. The second step was to evaluate the welding and mold materials after the initial selection of process and material had been made. The third step was specific environmental testing of the assembled cable connector systems after they had been terminated in semiautomated facilities. The basic conclusions of the tests can be simply stated. The use of the CO_2 laser for insulation ablation was found to have no detrimental effect on the dielectric characteristics of the organic insulation. The laser welds were found to have superior strength to normal welding. From welds which appeared to be only partial all the way up to 50% material burnout, they exhibited greater strength in a tension test than the basic copper track on the flexible printed wiring. The Hydantoin epoxy molding material was found to have excellent characteristics for moisture resistance. The Bisphenol epoxy formulation used for the Amp connector was found to have inadequate characteristics for the humidity environment.

Implementation

The value of a manufacturing technology program can only be realized with the reduction of results to actual utili-

zation in the manufacturing environment. Since this was recognized early in the program, a comprehensive plan for both internal and external implementation was prepared.

The internal implementation results as of December, 1980 are listed below:

1. AN/ALQ-131 (V)—Conversion of all FCC and FPW terminations to FLEXICON process, including those of prior "state of the art" techniques. **IN PRODUCtion**

2. APG-66—Advanced Signal Processor I/O Cable. **PRODUCTION 1981**

3. E3A-AWACS RADAR—On-board test equipment update. **PRODUCTION 1981**

4. AQUILA—Army RPV Sensor **PREPRODUCTION 1981**

Externally, the value to the industry in general has been seen from the large attendance (over 1600 people) and interest at industry meetings. FLEXICON has been a very beneficial manufacturing technology program for industry and DOD programs.

Intangible Benefits Not Estimated

The basic cost savings for military environment qualifiable connectors is shown in Table 1. These show the savings as they would be realizable in a fully automated facility. However, the intangible benefits in quality control and reliability have not been estimated. Those savings will be significant as in the predictable automation of any previously hand performed operation.

	Present Practice	FLEXICON
Connectors (mated pair)	$450.	$50.
Flexible Printed Wiring (4 layers)	80.	45.
Assembly (value added)	90.	4.
Maintenance Expenses	1.2	.2
$[C]_{ij}$	$620.	$99.

Table 1

Pitfall Avoidance

There are two areas in which attention to detail can remove two specific pitfalls. Both of these were worked around to permit the continuation of the program, and both point to probable design improvements in the connectors which can benefit actual connector use. These areas involve physical construction of the connector tabs and the use of molded block dielectric into which connector contacts are inserted at a later stage.

Several of the connectors which were studied had been designed for two rows of .050 inch connector contacts and four rows of .100 inch contact tabs for insertion into PWB's. As a result, the tabs were offset from the center of the contacts. When the contacts were reversed in the connector block to provide a dual row .050 inch tab configuration, they had very little space (.002-.010) between them. A redesign of this area on certain connectors will solve the problem.

The practice of molding the connector bodies as separate (from the contacts) items and assembling contacts in a subsequent operation created difficulties in the FLEXICON molding operation which were solved by "pin sealing". Care must be taken in connector selection and design of molds that the low pressure compound injection does not push epoxy into the connector contacts from the back of the connectors. If the dielectric block of the connector is molded around the contacts, there is no difficulty. Pin Sealing, if ultimately required, could be automated as a batch process prior to entry to the FLEXICON Processes.

Additional Development Recommended

Two specific additional developments have been recommended; both involve the molding operation. First, it is suggested that the use of material other than glass filled polyester be considered for connectors, and that cost effective alternatives be explored. This should be accomplished toward the end of being able to use the Hydantoin Epoxy (and its cure temperature) instead of the Bisphenol. Second, it is recommended that further materials research be performed in the epoxy area to try and improve cure times and temperatures for LIM (liquid resin injection molded) epoxies. Both of these would improve producibility.

Brief Status Reports

Project 8059. Salvage of Cannon Components by Electrodeposition of Metal. Gun tubes and other components of cannon are rejected and condemned due to excess stock removal or mismachining during fabrication. This project was conceived to develop a process to deposit additional metal on rejected components to compensate for this excess stock removal. Drawings and rejection reports of candidate components were obtained and the requirements for a salvage coating were determined. The design for a portable pump-thru plating system was made and specifications to purchase or fabricate components were completed. Plating materials include nickel, chromium, and iron cobalt. For additional information, contact T. Pochily, Watervliet Arsenal, (518) 266-5697.

Project 8060. Improved Manufacturing Processes for Final Inspection of Cannon Tubes. Purpose of this project was to develop an inspection process which uses mechanization and new technology to increase the rate of inspection for cannon tubes. Materials handling equipment has been acquired and specifications have been rewritten using new formats. A scope of work plan is being developed. For additional information, contact J. Antenucci, Watervliet Arsenal, (518) 266-5697.

Project 8062. Rapid Internal Threading. Producing internal metric threads in breech rings is a serious production problem because of both the techniques and tooling required. Conventional thread hobbing presents a production bottleneck, but current technology and recent tooling breakthroughs have expanded high speed threading considerably. Automated threading will be an efficient, economical replacement for current milling type hobbing processes. An industrial survey determined that "off the shelf" available equipment would not meet the needs of the project whose purpose was to establish such a capability at Watervliet Arsenal. A detailed equipment specification was written and contracting negotiations will follow. For additional information, contact G. Conlon, Watervliet Arsenal, (518) 266-5611.

Project 4062. Automated Manufacturing System for Mortar Increment Containers. The fabrication of the 60/81 mm propellant charge increment container is labor intensive and does not meet production rate requirements. The NC paper molding procedure was determined more adaptable to automation than the NC slurry vacuum molding procedure. Both vacuum slurry felting and paper molding methods were included in scope of work. Three contracts let to design automated manufacturing and assembly systems for mortar increment halves. FMC Corporation selected for design of both fabrication methods and Innova, Inc. for the development of the automated assembly system. Armtec awarded the production process optimization effort for slurry vacuum formed 81 mm M205 containers. For additional information, contact P. Bonnett, ARRADCOM, (201) 328-5839.

Project 7963. Group Technology + Cellular Manufacturing for Fire Components and Assemblies. Fire control manufacturing has experienced proliferation of manufacturing information, long setup times or multiple resetting of machines, under utilization of machines, long and uncertain throughput times, and excessive work in progress. Through establishment of group technology part families, machine groups, tool groups, and work groups, it would be possible to realize a reduced planning effort, less setup time, less work in progress, less scrap, and more effective machine utilization. MICLASS (system of classification and coding/group technology software) installed. Contract let to establish a pilot computerized design/manufacturing system based on group technology. The initial MIPLAN standard text and a design data retrieval code were prepared. Training for MICLASS and MIGROUP wer completed. The MIPLAN software was converted to operate on ARRAD—COM's computer system. For additional information, contact N. Scott, ARRADCOM, (201) 328-8430.

Project 8004. Co-Deposition of Solid Lubricants During Anodizing. Low friction, hardcoat surfaces are needed for aluminum components subjected to wear as bearing surfaces. To apply an electrolytic anodic coating while simultaneously depositing solid lubricant particles within the coating would produce the combination needed. Various aluminum alloy journals were anodized with a Sanford Hardcoat Processor and resistance measurements were made. For additional information, contact L. Gruss, ARRADCOM, (201) 328-2395.

Project 8005. Establishment of a Space Mechanical Plating Process. Elimination of embrittlement

causing hydrogen during electrochemical or chemical process to coat steel ordnance items was planned from development of a mechanical plating process. Various small parts were coated with cadmium, zinc, or combinations of these plus chromate and were subjected to salt spray tests. Project was completed and final report is available. For additional information, contact A. Gigliotti, ARRADCOM, (201) 328-5752.

Project 8010. Production of Acoustic Microwave Filters. Development of a production method capable of building 30 acoustic microwave filters per day rather than the present one or two per month was the objective of this project. An in-house effort at ARRADCOM, electron beam lithography was the technique used to produce resonators, opto-acoustic devices + microwave filters. Numerical control was used to achieve production rates. Polymethyl methacrylate was used as a substrate for electron resist technique. Flying spot scanner used in pilot line. For additional information, contact T. Chin, ARRADCOM (201)328-2936.

Project 8051. Application and Control of Machine Tools. Current procedures for the justification, selection, application, and maintenance of machine tools often are inadequate to avoid procurement of inefficient, unreliable machine tools. This project will establish an accurate definition of machine tool requirements in relation to component machining requirements. It will develop performance analyses and competitive performance evaluation criteria. Results from a previous mantech project were considered for application to the project. Hours of machine tool maintenance were related to required output. For additional information, contact R. Kirschbaum, Rock Island Arsenal, (309) 794-5363.

Project 8054. Improvement of Manufacturing Technology and Quality of Optical Scratch and Dig Standards. Present optical scratch and dig standards are difficult and expensive to manufacture, calibrate, and maintain. Project will improve processes used to form these. Laser scribing will be used to make lines in the metal die used to scratch standard. Plasma etching will be used to form dig standards. Phase II follow-on to be done by small business. Very wide application to Army hardware. For additional information, contact J. Salerno, ARRADCOM, (201) 328-3210.

Project 8057. Dual Rifling Broach Removal System. Present rifling equipment requires manual removal of broaches. After each of 32 passes the operator must walk from his station to the far end of the gun tube to remove them. This project's purpose was to develop an automatic broach removal device which will reduce operator time, safety hazards, and operator fatigue. A broach removal system was designed which used two heads to carry the broaches through the gun tube and interface with the rest of the mechanism. Interface problems prevented the use of a microprocessor for control of the operation. For additional information, contact J. Bak, Watervliet Arsenal, (518) 266-5611.

Project 8104. Improved Breech Block Manufacturing. The wide variety of machine table standards involves expensive and space wasting alternatives to specifically designed manufacturing processes. The purpose of this project was to develop a specifically designed manufacturing facility using a palletized system of fixturing, maximum tool efficiency, and reduced materials handling. This project is directed toward developing a facility employing state of the art flexible manufacturing system principles incorporating nonsynchronous production concepts. Breech block drawings and manufacturing production route sheets were studied to assess each machining operation that will be performed by the FMS on a 105 mm howitzer. A decision was made to purchase a flexible manufacturing system for installation at Watervliet Arsenal. Procurement is under way. For additional information, contact A. Wakulenko, Watervliet Arsenal, (518) 266-5611.

Project 8105. Establish Rough Thread Blanks for 8 Inch M201 Bushing. A single point tool now is used to produce the rough formed blank for step threads on step blocks. Time required is 13.9 hours. Possible applications of multiple slotting tools and milling offer a far more efficient metal removal process aimed at time/cost reduction. A combination of milling and multiple slotting was utilized to expedite stock removal; this approach had the most impact on reducing machining time. Component drawings have been completed to illustrate comparison of the present method to that being investigated. Equipment specification is in progress. For additional information, contact J. Bak, Watervliet Arsenal, (518) 266-5611.

Project 8120. Adaptive Control Technology (CAM). Inefficient use of N/C machine tools due to conservative programming is uneconomical. Also, the inability to monitor a multiplicity of tool forms characteristic of N/C machine capability is a limiting factor. This project's purpose is to perform an evaluation of a process called **ENERGY ADAPTIVE GRINDING.** To maximize the use of both N/C equipment and tools systems, current adaptive control technology will be extended to control the tool loads in small mills and drills so they can be performed in the same setups. For additional information, contact R. Meinhart, Watervliet Arsenal, (518) 266-5737.

Project 8106. Large Caliber Powder Chamber Boring. Powder chamber production on the 8 inch M201 cannon currently requires 14 hours for both rough and finish operations. In order to eliminate one grinding operation, this project was proposed to perform the finishing operation in the same setup as the roughing operation, but using as a cutting media diamond finishing tools which at very high speeds produce excellent surface finish. Electrochemical principles were used instead of hydraulics. Special boring bar system design drawings were completed and precision positioning system specifications were selected following thorough review. Testing of the system is in progress. For additional information, contact A. Wakulenko, Watervliet Arsenal, (518) 266-5611.

Project 3056. Electroluminescent Numeric Module. High contrast numerical readouts are required for sunlight legibility and full environmental operation in tactical equipment. Electroluminescent modules needed to fulfill this requirement are available only as small quantity, high cost, laboratory built samples. Thin film circuitry techniques and hybrid assembly procedures are used to achieve an efficient high yield manufacturing technology capable of producing reliable, fully militarized numeric display devices at reasonable cost for large volume usage. New methods for circuit bonding, cleaning, hermetic sealing, and packaging of 10,000 modules per month will be devised. For additional information, contact R. True, ERADCOM, (201) 544-5557.

Project 3057. High Stability Vibration Resistant Quartz Crystals. Current crystal resonators show frequency changes will acceleration. This is a serious problem where the resonator must operate in a vibratory environment. The consequences are especially severe when equipment must operate in a jamming environment. The doubly rotated quartz crystal resonators, particularly the sc-cut, have a much lower sensitivity to mechanical stress than the (singly rotated) at-cut. Based on research and development, additional information production techniques will be developed. The project will establish a commercial source for high stability sc-cut quartz crystals. Tasks include cutting, lapping, angle correcting and mounting. Each crystal will be sealed in a ceramic flatpack. For additional information, contact J. Gualtieri, ERADCOM, (201) 544-5413.

Project 8107. Creep Feed Crush Form Grinding. Fabricating the bracket slot on the 105 mm M68 breech ring is costly, currently milled with form tools in rough and finish operations. A new process being developed resembles the crush form abrasive machine for cylindrical parts, except the process is used to produce flat contoured surfaces. This procedure was proposed for producing the bracket slot. Following fixturing design for retention of the breech ring and development of engineering specifications for all major capital equipment to construct a 100 hp creep feed crush form profile grinding system, work was started to develop a new manufacturing sequencing, routing, and testing technique. Project is about 10 percent complete. For additional information, contact J. Rodd, Watervliet Arsenal, (518) 266-5611.

Project 3054. Production Methods for Multi-Layer Folded Circuits. Dense and highly reliable electronics are required for military systems. The conventional multilayer rigid circuit high density packaging is limited by special interconnections and other problems. Hughes Electronics will select the material, process specifications and standards for the multi-layer, multifolding rigid-flex circuit boards. A user readout board was deleted from the effort. For additional information, contact J. Johnstone, CECOM, (201) 542-4252.

Project 9835. Integrated Thin Film Transistor Display. Semiconductor display arrays require compact yet complex drive circuits. A multistage vacuum metallizing system is needed. It was necessary to

develop mask mounting and changing techniques, also, the need to develop methods for cleaning and reinserting masks without changing registration. Display panel is to have peripheral circuits. Aeroject had stress problems in the upper stacks that caused peeling in black CDTE enhancing the layer. Upper structure polyimide layers are being rearranged stop stress and electrically isolate interconnections and ground plane. The final masks are being prepared. For additional information, contact M. Miller, CECOM, (201) 544-5205.

Project 9851. Tactical Miniature Crystal Oscillators. State-of-the-Art precision quartz oscillators do not meet the performance, producibility, and cost criteria needed for future equipment. Tactical Miniature Crystal Oscillator (TMXO) is high performance, but it requires new production techniques. It was necessary to establish quality control procedures and cost effective processes for assembly, outgassing, sealing, and testing production TMXO. Also, to design and fabricate special fixturing and tooling for implementing manufacturing processes unique to TMXO. The project will establish high vacuum sealing, metallization, brazing, bonding, baking, and cleaning processes for ceramic flatpack enclosed quartz crystal oscillators. For additional information, contact S. Schodowski, ERADCOM, (201) 544-2602.

Project 9898. Ruggedized Tactical Fiber Optic Cables. The conventional metallic conductor cables do not provide secure, reliable, ground based communications. Metallic conductor cables are to be replaced with Fiber Optic Cables. The number of repeaters required would be reduced. Fiber optic cables offer advantages over conventional metallic cables in weight, space needs, repeater number, immunity to EMI, and crosstalk. ITT Electro-Optics is improving production equipment to fabricate fiber optic cable for secure ground based communications. They have installed a new highspeed optical cable strander, serving line, and polyurethane jacket extrusion line with full automatic control; however, the jacket cracked at low temperatures. Special extrusion and molding dies have been added to the jacket fiber optic cable bundles. Samples are being tested for low loss and mechanical strength. For additional information, contact L. Coryell, CECOM, (201) 544-4090.

Project 3012. Infrared Source for AN/ALQ-144. The present infrared source for the AN/ALQ-144 does not emit enough radiation in Band No. 4. The object is to establish production processed for machining the boron nitride radiator, grinding the sapphire dome, assembling, burn-in, and test. The application used is an infrared source. ILC technology established graphite heater machining methods for improved infrared sources with yields as high as 85%. Chemical vapor deposition of boron on the elements was optimized for high reliability. For additional information, contact J. O'Connell, ERADCOM, (201) 544-5407.

Project 3026. High Pressure Oxide Integrated Circuit Process. Conventional oxidation of thick silicon dioxide layers requires excessive time or temperature. For oxide isolated bipolar circuits, 1200 degrees for over 12 hours is required. There was a need to establish production techniques for high pressure oxidation of silicon layers. Rapid oxidation rates obtainable permit either reduction of time required to one fourth or a temperature decrease to less than 900 degrees. Electronic Technology and Devices Laboratories (ETDL) is developing a high pressure dry oxidation chamber with autoclave engineers. Components of the equipment will be installed at ETDL as they become available and will be demonstrated to industry. For additional information, contact R. Zeto, ERADCOM, (201) 544-4872.

Project 3505. High Contrast Cathode Ray Tube. High contrast cathode ray tube avionic displays for day-night vision goggles are currently unavailable. Optical filters are environmentally limited for this application. Phosphor techniques are available but optimization and economics have not been shown. The use of optimized bilayer transparent phosphors with a black abosrbent layer provides the high contrast display for the several modes. Optimization of phosphor techniques for 5 inch and larger CRT's will be economically justified. The contractor will develop an automated process for depositing transparent phosphor films with a black light absorbing layer to provide economical, high contrast sunlight-legible cathode ray tubes. For additional information, contact P. Krzyzkowski, ERADCOM, (201) 544-5547.

Project 3501. Third Generation Photocathode on Fiber Optic Faceplate. The form, fit, and function

replacement of 2nd generation 18 mm and 25 mm devices with 3rd generation product improvement will require that a production technique be available for fabricating GA-AS photocathodes on fiber optic faceplates. The plan is to provide a production process for 25 mm fiber optics faceplates with proper coefficient of expansion to match GA-AS. Seal GA-AS to the fiber optic and activate photocathode to high sensitivity using a high rate of production techniques. IIT's EIP division delivered a sample image intensifier photocathode using a vapor epitaxy growth system. Cosmetic and sensitivity deficiencies occur when bonding fibers into the faceplate and heat cleaning the substrate material. For additional information, contact K. Villhauer, ECOM, (703) 664-1725.

Project 9738. Epitaxial and Metallization Processes F/GAAS Impatt Diodes. There have been no rugged, low cost, highly reliable microwave sources and amplifiers for Army application. A new technique has reduced research and development procedure to a manual technique with pseudo controls. Purpose is to augment the present manual procedures with an automatic system that utilizes a feedback control scheme to regulate process conditions. Microwave Associates applied automatic controls to the epitaxial growth and doping thru control of gas flow and deposition rates. Reduced operator control and increased use of feedback resulted in improved profiles and performance of BAAS diodes. For additional information, contact V. Higgins, ERADCOM (201) 544-2855.

Project 9754. Continued Cycle Processing of Quartz Crystal Units. High Stability ruggedized crystals are not available at low cost due to the unavailability of the required processes and equipments at commercial sources of quartz crystal units. The project was to establish the continuous cycle vacuum processing and associated technologies at a commercial crystal company. General Electric Neutron Devices Company was solicited to measure crystallographic angle using laser assisted X-ray. Crystal resonators have been successfully fabricated. Several hundred engineering samples have been processed and fabrication of confirmatory samples is under way. For additional information, contact J. Vig, ERADCOM, (201) 544-4275.

Project 9766. High Voltage Insulating Layer Deposition for Thick Film Circuit. The present process for depositing an insulating layer on the thick film circuits to separate high voltages within the circuit is inadequate and costly. This project is to establish a mechanized process to passivate the various circuit components. Erie Technological Products built thick film multiplier modules that operated efficiently. The building of new design thick film hybrid multiplier modules showed undesirable high charging currents, but these problems were resolved by reducing the size of capacitor electrodes. For additional information, contact J. Evans, ECOM, (703) 664-1551.

Project 9793. Production of Intagliated Fiber Optic Phosphor Screen. Fiber optic screens lose photons where they strike the glass rather than the phosphors. This project was to etch away the cores in a funnel shape and deposit phosphors in the funnel to provide higher input efficiency. ITT Electro Optics Products Division handled the project and established processes to etch out the cores of optic fibers, metalize the walls, then deposit phosphor and a thin layer of aluminum to fill the etch pits. They are using the processes to make fiber optic phosphorus screens for the AN/VVs-2D rivers sight MMT project. For additional information, contact W. Markey, ECOM, (703) 664-1725.

Project 9805. Auto Microcircuit Bridge PDN Measure of Quartz Crystals. The crystal impedance meter requires updating to allow accurate measurement of crystal characteristics, regardless of temperature and frequency. The purpose of the project was to build a temperature test chamber, automatic crystal transport, and frequency measuring and data collection equipment. Hughes handled the project and developed an automatic quartz crystal parameter measuring system to replace obsolete crystal impedance meters. Control board noise was reduced from 800MV to 5MV. Calibration elements were system tested and software is nearly completed. For additional information, contact G. Malinowski, ERAD—COM, (201) 544-2325.

Project 3510. Transducer Process Technology for MW Delay Lines. The parameters for describing the actual processes required for high quality transducers have not been documented. This results in production halts and low yield. The objective is to document the

materials, processes, controls and techniques necessary to fabricate high quality thin film piezoelectric transducers. The parameters will be incrementally shifted so that a noncritical stable plateau region is defined. Westinghouse will establish manufacturing techniques for fabricating high quality zinc oxide transducers at a yield of over 50 percent. Westinghouse ordered equipment to clean quartz or sapphire crystals, sputter on zinc oxide piezoelectric material and chrome-gold conductors, and photoetch to define the lines and areas. Westinghouse is not qualified to deposit series delay line transducer. Westinghouse completed an expanded test schedule on zinc oxide piezoelectric transducers. Tests show memory effect may be due to oxygen content. for additional information, contact S. Lieberman, HDL, (202) 394-3190.

Project 3504. Infrared Color Correcting Glass. The present common module infrared imagers used with the Army Fire Control System require aberration correcting lens elements. There is no substitute for Texas Instruments Proprietary 1173 infrared glass except for the newly developed AMTIR-1. The intent is to establish the processes and methods for manufacturing this new glass in sufficient quantity to satisfy the Army's production demands. Amorphous Materials, Inc. is establishing casting processes for producing uniform GE-AS-SE glass in 10 inch diameter plates for infrared systems. Domed mixing chambers were designed and used. For additional information, contact E. Lambert, ECOM, (703) 664-1861.

Project 5110. Common Module Detector Array. Mercury-Cadmium Telluride Detector Arrays are now hand lapped and polished. Contact masking is used for photolithography and wet etching for delineation. Also, gold wiring is used for leadouts. These are labor intensive and nonuniform. The project purpose was to use semiconductor industry practices of batch machine lapping and polishing of HG-CD-TE wafers, projection photomasking, plasma etching, ion beam milling, leadout metallization, and plating. These should provide uniform results. Santa Barbara Research Center documented every step in the array fabrication process; 53 steps are candidates for improvement. Prototype lapping and polishing equipment was installed and used on 50 samples. Cold shield tooling was also installed. For additional information, contact E. Lambert, ECOM, (703) 664-1861.

Project 5147. Production of Detector Grade Polycrystalline Silicon. There is a shortage of high purity trichlorosilane material used for growing into polysilicon rods for vacuum float zoning into high resistivity single crystal boules. High purity and high resistivity silicon is needed for photodetectors for munitions. This project was to establish a domestic supply of high purity polysilicon and refine out unwanted phosphorus and arsenic from trichlorosilane. Hemlock Semiconductor produced 160 kilograms of 25 mm detector grade polysilicon for use in laser seeker detectors. A contract is being considered for producing 64-72 mm polysilicon using a proprietary vapor phase purification process. For additional information, contact R. Savage, ERADCOM (201) 544-2887.

Project 5042. Low Cost Third Generation Image Tube Power Supply. Existing manufacturing procedures for high voltage power supplies for image tubes are inadequate to achieve low production unit cost with high perform ance and reliability. The purpose of the project was to establish automatic assembly and test procedures to produce low cost power supplies for high density voltage stress requirements. Litton grew three 50 mm diameter ND-YAG crystals to 64 mm length. Boules showed some defects but were adequate to fabricate 12 sample laser rods. For additional information, contact W. Comeyne, ECOM, (703) 664-1064.

Project 5094. MMT 8K Bit MNOS BORAM. The present 2K bit memory chips cannot store adequate data. An 8K bit chip has been developed in research and development and needs to be packaged and production engineered. The idea was to establish a production base for building memory modules consisting of hybrid circuits with sixteen 8K bit chips. Westinghouse was to optimize production techniques for packaging semiconductor memory wafers. They delivered a sample lot of 16 chip hybrid circuits for 8K block operated random access memories. A production rate of 500 16 chip hybrid memory circuits per month is desired. For additional information, contact H. Mette, ERADCOM (201) 544-4995.

Project 9877. Light Emitting Diode Array Common Modules. A lot of hand assembly, wiring, testing, and resistor trimming is used in building LED modules. The project is to establish methods for producing a LED chip with 180 resistors to balance each diodes output. Spectronics, Inc. has been selected to establish a multiwafer epitaxial growth technique and improve component fabrication for Gallium Arsenide Phosphide material used in LED array common modules. They modified two automatic reactors to grow GA-AS-P material for light emitting diodes. Wafer characteristics were correlated with reactor conditions. Manufacturing procedures were written. For additional information, contact M. Jasper, ECOM, (703) 644-1861.

Project 9873. Antenna Pattern Measurements Using Near Field Techniques. Phased array antenna transmission and receiving patterns are determined by the individual elements. Testing the pattern of a 6,000 element antenna is lengthy and costly. The purpose of the project is to use automatic near field measurement utilizing a probe near the antenna and apply output to a computer for processing. Also to develop performance map for QC documentation. Hughes Aircraft will build and test a system for measuring the radiation pattern of phased array antennas for TPQ-36 and -37 mortar and artillery locators. The entire system , which consists of four major elements, has been assembled and is operational. A group of AN/TPQ-36 antennas has been measured on both the near field system and on a far field range. For additional information, contact J. Borowick, ERADCOM, (201) 544-5143.

Project 9812. Split Cycle Stirling Cooler. Man-portable viewing systems requiring more than a two hour mission time must use a Joule-Thompson cryostat and high pressure gas cartridges to cool their IR detectors. The purpose of the project is to eliminate problems by using a split cycle stirling cooler. Martin-Marietta Corporation installed new motor stators in the coolers and put them on life test after the motors had earlier failed. Martin learned how to shape, finish, and handle thin metal stampings. They completed work on split-cycle stirling coolers for use with common module IR detectors. Precision seals and crankcase parts were made. A production rate of 10 coolers per week was demonstrated. For additional information, contact S. Horn, ECOM, (703) 664-1345.

Project 9807. Processing High Stability Quartz Crystal Unit. Stresses due to thermal shock, mounting, bonding, electrodes and acceleration prevent crystals from achieving the stabilities required by secure communications and navigation systems. This project is to develop cost effective techniques of manufacturing doubly rotated resonators. The emphasis will be on automation techniques for cutting, X-ray orienting, and angle correcting doubly rotated plates. Gend, a Goco facility, will extend pilot line capability to include high stability quartz crystals. General Electric Neutron Devices Department will extend the capability of its crystal cutting, polishing, plating, and packaging facility to the project. Gend is expanding the vacuum quartz crystal processing equipment. Modifications will increase fixture vacuum and provide greater control of crystal cutting, lapping, and polishing. For additional information, contact J. Vig, ERADCOM, (201) 544-4275.

Project 3532. Molten Salt Lithium-Chloride Battery. The present lead/acid and nickel/iron batteries often need recharging in order to complete an eight hour shift. This project is to establish methods for producing in quantity lithium chloride molten salt batteries. The cell and battery were redesigned to meet special needs of Army forklift program. The battery will now be constructed with felt rather than fabric BN separators in the cells. New felt separators developed are less costly and give improved performance. EPI is now designing the battery insulation box. Cells with felt separators have been operated for over 100 cycles. For additional information, contact E. Dowgiallo, MERADCOM, (703) 664-5309.

Project 9909. Production Techniques for SI MW PWR Transistors. As the concentration of integrated circuits increases the heat density is reaching the point where it will destroy the semiconductor devices. The project purpose is to replace the present packaging devices with units having a high percentage of diamond material so as to achieve a greater thermal transmission. Microwave Semiconductor Corporation will develop production methods for silicon microwave power transistors using base implantation, shallow emitter diffusion, stepped electrode metallization, plasma etching, and self-aligning metallization. For additional information, contact R. Gilson, ERADCOM, (201) 544-4917.

KAZYS NAVASAITIS is a Materials Engineer at the U.S. Army Tank-Automotive Command. He received a B.S. in Chemical Engineering in 1961 and, under a Department of the Army program of long-term training and education of civilian employees, completed the graduate program in Chemical Engineering at Wayne State University in 1973. A licensed professional engineer, Mr. Navasaitis for the past 20 years has been responsible for the development and application of many specialized protective coatings utilized in corrosion prevention for existing and new tactical vehicle systems and has served as a consultant to other government agencies and industries. He presently is involved in developing corrosion resistant sheet metal components for wheeled vehicles.

This project was conducted by Avery J. Austin and Nicholas F. Hayes of FMC Corporation, Ordnance Engineering Division, 1105 Colemn Avenue, San Jose, CA 95108.

A New Twist!

High Strength Torsion Bars Better Protected

Use of paint primer and polyethylene tape wrapping to protect Army vechicle torsion bars from corrosion has been discontinued, since a plastic coating has proven more effective. The decision to effect a change resulted from findings of a 15-month MM&T program conducted by FMC Corporation for the U.S. Army Tank Command in which various organic and inorganic coating candidates were evaluated.

Bars Universally Used

All current tracked military vehicles in the U.S. inventory, including the M1 Main Battle Tank and the M2 Infantry Fighting Vehicle, use high strength torsion bar springs in their suspension systems. Recent improvements in vehicle cross country mobility have been achieved in large part by increasing roadwheel travel and developing torsion bars capable of operating at higher stress levels. As a result, bars have become more sensitive to surface damage such as that caused by corrosive pitting or damage that occurs when tools or other objects accidentally strike a bar during vehicle maintenance or repair operations.

The current method of protecting high strength suspension torsion bar springs specifies that a coating of

NOTE: This manufacturing technology project that was conducted by FMC Corporation was funded by the U.S. Army Tank Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The TACOM Project Engineer is Mr. Kazys Navasaitis, (313) 574-5814.

primer paint be applied directly to the precleaned body of the steel bar (but not on the splines); this is then followed by a spirally wound layer of self-adhesive polyethylene tape which is applied with a 50% overlap. Thus, a double layer of tape resists abrasion and protects the primer paint from damage.

Experience has shown that this tape/primer system does not provide adequate protection.

Torsion bars are located in the vehicle bilge area near the hull bottom plate. Diesel fuel, oil, water, and other liquids may leak on them. Diesel fuel attacks the tape adhesive and causes loss of tape integrity. The primer paint is then exposed to moisture and abrasive damage. In addition, maintenance personnel sometimes walk on the torsion bars or accidentally drop tools and vehicle parts on them. Figure 1 shows some examples of damage. Although inhibitive pigments in the red oxide or zinc chromate primer offer the steel torsion bar some degree of corrosion protection, paint adhesion deteriorates after extended contact with moisture. This then permits corrosive attack on the torsion bar surface. The combination of corrosion and continual stresses tends to propagate corrosion pits into cracks, and these flaws become fracture initiation sites which can lead to premature bar failure. If corroded areas are detected during maintenance inspections, the affected bar is removed from service before failure can occur.

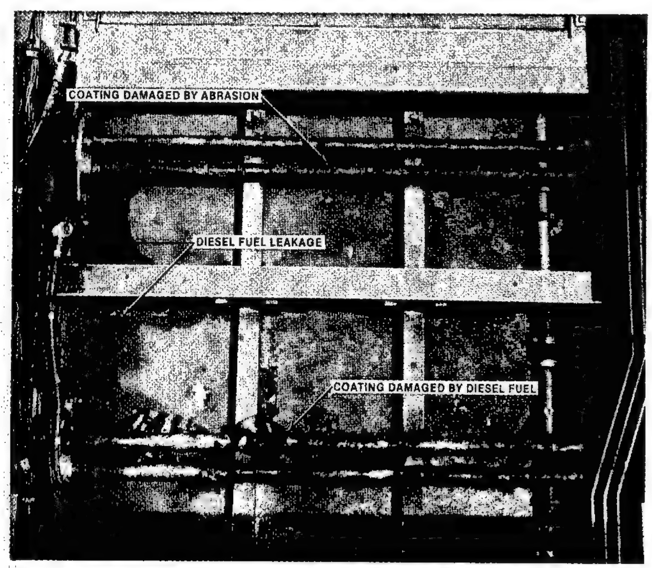


Figure 1

2% Cost Increase Yields Large Dividends

This study showed that Plastisol (a plastic coating) when applied by the vertical dip method is the most cost effective coating. Based on the current M113A2 torsion bar cost (300M material with tape and primer coating) of approximately \$170, the Plastisol coating will increase bar cost by less than 2% while increasing bar life by 146%. Even greater savings can be achieved for the M48/M60 bar where the Plastisol coating costs less than tape and primer.

The Testing Program

This program was divided into two phases: Phase I consisted of the selection of test methods and laboratory testing of the current tape and primer system and eight candidate coatings; Phase II consisted of performance verification testing.

Coating Characteristics Good

To evaluate methods for preventing corrosion of steel, a review of coating methods and commercially available products was performed by the Coating Section of the FMC Materials Engineering Laboratory. A successful high strength torsion bar body coating should exhibit the following characteristics:

- Good adhesion to steel
- Corrosion resistance
- Hydrocarbon resistance

- Flexibility
- Abrasion resistance
- Impact resistance
- 350 F maximum process temperature (so that processing will not affect bar temper)
- Cathodic protection (if a metallic coating).

After an analysis of the specifications and cost data, it was determined that the following types of coatings offered the most promise for this application:

- **Metallic coatings.** which provide cathodic protection to prevent or reduce corrosive attack.
- **Inorganic and organic metal filled coatings,** which afford some degree of cathodic protection.
- **Plastic coatings** of a resilient nature, which (1) protect by preventing moisture or corrosives from contacting the steel surface and (2) have excellent mechanical damage resistance.

One or more of each coating type was selected for evaluation.

Coatings Subjected to Seven Tests

Eight coatings (plus the tape/primer system) were selected for evaluation. They were applied to seven standard 0.030-inch thick type R-412 steel panels (56 panels total) and three 0.25-inch thick hardened steel plates (56 panels total) by vendors or by FMC Materials Engineering Laboratory following vendor supplied application specifications. Individually coated panels were subjected to the tests described below and rated to permit an evaluation of each coating in each individual test:

- **Salt spray resistance** using scored panels and 5% salt spray at 95 F (coatings were judged by hours of continuous exposure until corrosion was detected.)
- **Humidity resistance** using scored panels and 100% humidity at 100 F (coatings were judged by hours of continuous exposure until coating blisters or rust spots were detected.)
- **Flexibility** with a 1/4-inch diameter bar for 90 and 180 blends (coatings were judged to have failed if the coating cracked; failed coatings were subsequently tested on a 1-inch diameter bar; ratings were either ''passed'' or ''failed''.)
- **Adhesion** using a scoring tool to inscribe the coating with a crosshatch pattern; adhesive tape was then applied to the squares and removed rapidly (a rating system of numbers was used with''5'' for best adhesion and ''0'' for no adhesion.)
- **Abrasion resistance** with the Taber Abraser using CS17 wheels, 1,000 grams load, and operating for 100 cycles (coatings were judged by milligrams of weight loss per 100 cycles.)
- **Immersion in diesel fuel** at room temperature for seven days (coatings were rated as either ''unaffected'' or''affected'' with changes detailed.)
- **Impact resistance** evaluated through the use of a chisel-edged, hardened tool (Candidate coatings were applied to hardened steel plates. Hardened plates were used to simulate the resistance to denting provided by a torsion bar because any deformation of the metal subsurface could cause loss of coating adhesion. This test was meant to provide a deliberately severe ''worst case'' impact condition.)

Coatings Ranked

Candidate coatings were ranked by assigning comparative values based on initial laboratory investigation tests. Values ranged from zero (lowest rating) to ten (highest rating); it was assumed that each of the seven tests performed was of equal importance. Ranking based on total points is shown in Figure 2, with the effectiveness baseline coating (tape and primer) given at the top for comparison.

On the basis of this analysis, testing of the four lowest ranked coatings was **discontinued.**

Coating	Salt Spray Resistance	Humidity Resistance	Flexibility	Adhesion	Abrasion Resistance	Immersion in Diesel Fuel	Impact Resistance	Total
Tape & Primer (Effectiveness baseline)	10	10	10	10	6	0	2	48
Elastuff 701 Polyurethane	10	7	10	10	10	10	10	67
Plastisol	5	7	10	10	9	10	10	61
Elastuff 504 Polyurethane	10	5	10	10	4	9	10	58
Ivadize	8	3	10	10	7	10	10	58
Injection Molded Polyurethane	5	7	10	10	4	10	10	56
Carbozinc SP81	10	10	0	0	8	10	10	48
Dacromet 320	3	4	10	10	0	10	10	47
Alumazite Z	2	2	10	10	5	10	0	39

Figure 2

Cost Effectiveness

Next, cost data obtained from coating manufacturers and commercial coating vendors was examined. Coating costs were based on a yearly quantity of 10,000 bars and include tooling costs. Figure 3 presents unit costs for coating M113A2 and M48/M60 torsion bars with tape and primer and for the four most effective candidates. After evaluation of both cost and effectiveness factors, Plastisol and Elastuff 701 were selected as the most promising candidates.

Plastisol and Elastuff 701 were subjected to endurance testing, induced coating/corrosion damage, and enhanced statistical analysis (using the Weibull Maximum Likelihood Estimator technique).

On the basis of application costs, results of the initial laboratory investigation, and protection level demonstrated by endurance testing, Plastisol was the most cost effective coating tested. It was, therefore, selected for performance verification testing (Phase II).

Coating	M113A2 (P/N 12268689)	M48/M60 (P/N 7359890)
Tape and Primer (cost baseline)	$ 4.25	$ 8.50
Plastisol	6.88	7.80
Elastuff 701	11.49	19.22
Elastuff 504	14.95	25.08
Ivadize	13.50	29.00

Figure 3

Performance Verification

The objective of Phase II was to verify that the Improved Coating System (Plastisol) which was determined to be most cost effective in Phase I provides an improvement in corrosion protection to production torsion bars when compared to the current tape and primer system. This task was accomplished through performance of two endurance tests employing a total of sixteen production M113A2 torsion bars.

The M113A2 torsion bar is designed for a 160,000 psi stress level. With this in mind, an outer fiber shear stress range of 9,000 to 180,000 psi in the body section was selected for endurance testing to ensure that failures would occur in a reasonable length of time. This range corresponds to 6% to 113% of design stress. Sinusoidal motion with continuous load control was employed during each test. A modification was made to mount M113 torsion bar anchors on pins to permit self-alignment, thereby removing the possibility of induced bending stresses which may have contributed to Phase I spline failures.

All bars were subjected to the standard damage/corrosion method prior to endurance testing. Tape and primer coated bars were tested first to establish an endurance life for bars that had sustained a corrosive attack at the damage sites. Plastisol coated bars, effectively protected from corrosive attack, were subsequently life tested and results of the two groups were statistically compared.

Endurance Analysis Via Computer

Endurance analysis was performed using a computer program, again employing Weibull Maximum Likelihood Estimator techniques. Shape parameter determines the relative shape of the density function. The low shape parameter (1.8532) exhibited by tape/primer coated bars skews the failure distribution toward early life failure. Figure 4 is a computer generated representation of the probability density function (PDF) for this case. The mode parameter noted on Figure 4 is the most frequently occurring life for tape and primer coated bars.

Figure 5 presents a similar representation of the PDF associated with the Plastisol coated bars. Comparison of curves in Figures 4 and 5 reveals a distinct difference in failure form. Tape and primer coated bars appear to have a short life (due to corrosion) as indicated by the low shape parameter (1.8532), whereas Plastisol protected bars with a much higher shape parameter (5.1587) have a longer life and tend to fail from fatigue. Note also that the mode parameter for Plastisol (41,881 cycles) is shifted away from the early failure that is exhibited by the tape/primer system (17,036 cycles). This shift represents a 146% increase in the most commonly expected life for Plastisol protected torsion bars. Further proof of increased life is provided by the fact that all Plastisol protected bars failed in the splines, indicated that corrosion did not penetrate the Plastisol, whereas all tape and primer coated bars failed at body damage/corrosion sites.

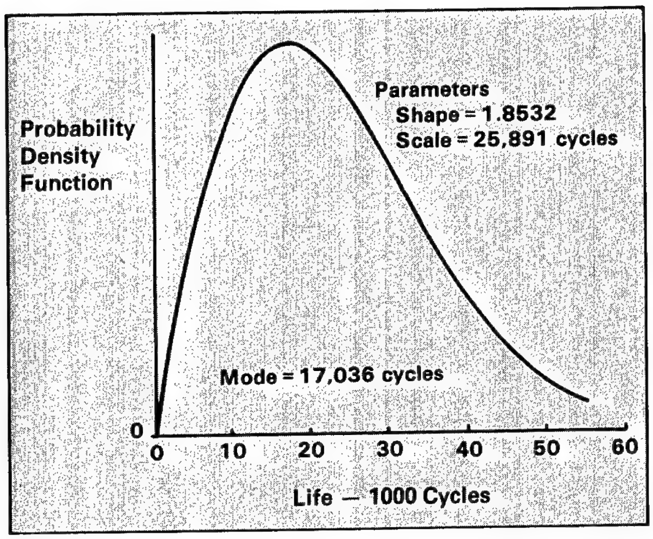


Figure 4

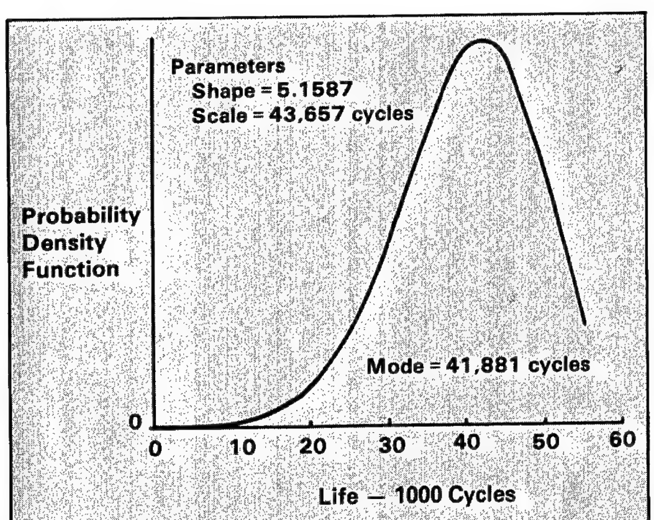


Figure 5

Time For A Change

This 15-month investigation leads us to the conclusion that the Requirements Section of specification MIL-S-45387, Torsion Bar Spring Suspension, must be revised:

- Discontinue the use of tape and primer as a torsion bar coating system.
- Replace tape and primer with the Plastisol system.

Maintenance inspections are few and far between during actual combat.

Benefits of the steady advances in manufacturing technology are certainly well known to ManTech Journal readers. Industry is reaping large dividends through improved productivity and lower costs. Society benefits through more and better products and through improvements in energy conservation and resource and waste management that help preserve our way of life.

However, technology growth is also creating at least one major problem for the manufacturer—keeping technical and production personnel abreast of advances in manufacturing materials and processes, just in their own plant, is a problem faced throughout industry. Manufacturers are finding that high technology is only as good as the people who support it. As technology advances, the skills and understanding of manufacturing personnel must keep in step if we are to take full advantage of potential improvements.

Recognizing this need, management at G.E.'s Aircraft Engine Group in Lynn, Massachusetts has developed an in-house manufacturing technology training program designed to help employees better understand the technology applied daily in their shops and laboratories. Both the company and the employees benefit from the courses in this program, which are administered and taught entirely by plant personnel. After completing a course, manufacturing personnel are better equipped to meet day to day problems in production and to further improve the the manufacturing processes to meet long-range goals. At the same time, they are better prepared to seek personal advancement within the organization. A further benefit is that most of the courses carry college accreditation.

Industry Model

The G.E. plant at Lynn, with about 8,200 employees producing jet engines, probably provides a good general model of training needs throughout U.S. industry. Most of the issues that led to a dramatic training effort there during the past few years are common to manufacturing operations across industry. These are:

- The proliferation of new manufacturing materials and processes
- The widespread and necessary use of the computer, which is an unfamiliar, sometimes frightening, tool to some of the work force
- The age of the experienced work force and the pending retirement of many key experts
- The number of young, new replacements and their lack of manufacturing experience
- The demands on the company to rapidly assimilate representative percentages of women and minorities into the work force.

Keeping Abreast of Technology

G.E.'s ManTech Training Program

RAMONA J. MARTINEZ is Organization and Manpower Representative for sections of AEBG Manufacturing, Lynn, Massachusetts. Ms. Martinez joined General Electric Company in 1978 as Manager of Professional Personnel Development in Lynn, and following that, served as O&M manager for the Small Commercial Engine Department and as the AEG-Lynn Ombudsperson. Prior to joining GE, Ms. Martinez was Director of the Montessori Education Department of Xavier University in Cincinnati, Ohio. She holds an A.B. from the College of St. Elizabeth in New Jersey and her M.Ed. from Rutgers University.

JOHN I. HSIA is Manager of Manufacturing Technology Operation of the Aircraft Engine Group of General Electric at Lynn, Mass. He is responsible for all manufacturing related activity on advanced development engines including total program management, also manufacturing education and training. Prior to this he was responsible for manufacturing engineering in the Lynn plant. Mr. Hsia joined G.E. in 1955 after two years of metal cutting research at MIT, where he received his B.S. in Metallurgy in 1953. With G.E. he has worked primarily with materials and processes for design and manufacture of jet engine components.

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturing Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

Facing these problems, in 1977 the Manufacturing Division at Lynn organized a group to examine some of the issues and outline an approach to their solution. The best approach seemed to be a concentrated attempt to deliver as much technical training as possible in the shortest amount of time to fairly large numbers of the plant's manufacturing managers and key production personnel. Upon investigation of other programs, the committee found no institutional training that would respond effectively to the plant's specific technical needs and set of requirements. They also determined that expertise in many relevant processes used in engine production was to be found primarily in-house.

Identify Three Levels of Need

Taking these committee findings, the Lynn plant set out to organize their own manufacturing technology training program. With some careful reflection, analysis, consultation, and application of common sense, they decided that employee needs were centered on three different levels. These may well typify training needs for industry as a whole.

First, many people needed a very basic, conversational level familiarity with manufacturing materials and processes. These people included new, young personnel in product control, product planning, purchasing, and product support. As a group, they suddenly comprised a much larger percentage of the work force than they had previously. However, they lacked sufficient background to be assimilated quickly enough to replace those leaving through attrition; even the vocabulary of manufacturing was lacking. Obviously, a specific training effort was needed to bring these people up to speed.

Second, there was a large group of middle managers with a general non-specific foundation of information and a sound experienced-based working knowledge of one specific area. Their overall knowledge of engine manufacturing technology was not sufficient to permit flexibility in assignments and or to encourage career mobility. This group required a different quality and scope of information than the first and, consequently, a separate training curriculum.

Third was a smaller number of "experts" in the company with identifiably different needs. These people were specialists in various manufacturing technologies and were expected to be up to date with the latest "state of the art". Quite often they would also be working on a new development activity in their area of specialty. In addition, there are manufacturing method specialists whose training consists of many years of on the job experience in the shops. In neither case did in-house training seem applicable.

Responsive Program Adopted

In response to these identified needs, the Manufacturing Operations Department at Lynn launched a Manufacturing Materials and Processes training program directed at those on the first two levels. This program brings together proven training techniques developed since World War II by the military, the most sophisticated video training techniques found on the market, and the knowledge of G.E. experts in the relevant manufacturing processes.

To date, some 14 courses, most of them college accredited and all unique to manufacturing technology operations, have been produced. They include a first-level introduction to various basic materials and processes and a second-level series, which gives in-depth information for the manager needing specific information to be effective in a given area. They range from an introduction to casting to a 1-year study of the manufacture of fabricated parts.

Instruction Optional

Although there are no requirements for employees to take these courses—they are purely elective, with concurrence of an employee's manager—completion of a particular course or courses is often listed as a desirable qualification for certain positions. Thus, employees looking to career advancement have an incentive to participate in the training program. Self improvement, the knowledge that one will be better able to handle job responsibilities, and the chance for college credit are other incentives.

All courses are taught by manufacturing experts from the Lynn staff. Before they begin teaching, these people receive training on teaching techniques. The plant's Professional Personnel Development Department manages and directs the training program and provides necessary support and teaching aids.

Covers 13 Topics

The 15-week Level I course covers the manufacturing materials and processes used in jet engine production at Lynn and includes 13 modules. These are:

- Metallurgy
- Metal Processing
- Heat Treating
- Joining
- Sheet Metal
- Conventional Metal Removal
- Electrical Discharge Machining
- Nonconventional Metal Removal
- Cleaning
- Coatings
- Computers
- Assembly and Testing
- Blueprint Interpretation

Students entering the course may take a self-study program and then take a proficiency test covering all 13 modules. If they score 80 percent or better for any module, they will not have to attend the class session covering that area. The tests also give the student a preview of the type of material to be covered. An example of some test questions for the casting module is shown.

Students in this self-study course spend up to an hour each week viewing videotapes or slide programs of various processes which are available in the Learning Resource Center at Lynn. Students are also given handouts to read before attending each week's class sessions. At the weekly classes:

- The instructor summarizes material from the videotape and handouts
- Students have the opportunity to ask questions of the instructor
- A brief test on the module is given.

Figure 1 is a flowchart of the entire process for the Level I course. To date, 384 people have participated in this program.

Level II More Detailed

Each Level II course provides in-depth technical information about a specific manufacturing process or family of processes. These courses run for 6 to 8 weeks and generally involve 10 to 20 class sessions. As with the Level I course, the student may take a proficiency test before starting a course and many get course credit based on the result of that test. Level II course are geared to exempt manufacturing personnel and give the student the knowledge needed to advance in the manufacturing organization. The students are provided with text material and curriculum guides for self instruction prior to class sessions. The classroom sessions emphasize discussion of the written material with the student gaining insights from the expert instructor, or instructors, and from each other.

Courses in the current Class II curriculum include:

- Conventional Metal Removal—covers basic machinability theory; chip formation; cutting tool forces and their effect on tool performance; turning feeds and speeds relative to required surface finish and part integrity; drilling, boring, milling, and grinding capabilities; and application to specific parts.
- Numerical Control—provides an understanding of the application of numerical control machines by covering numerical control history, lathe specifications and tooling, tape coding, interactive graphics, typical problems, and information about computerized coordinate measuring machines.
- Electrical Discharge Machining—covers principles of process operation; effects of process parameters on machined dimensions, surface characteristics, metal removal rate, and tool wear; selection of parameters for machining operations; process capability; examples of typical machining operations and

Sample Proficiency Test Questions — Castings

The most common means of casting parts for aircraft engines is:

a. investment casting
b. sand casting
c. die casting
d. permanent mold casting

The ______ is the portion of the mold through which molten metal directly enters the mold cavity.

a. gate
b. sprue
c. runner
d. mouth

The interior of castings are usually shaped after the casting has cooled from the molten state.

a. true
b. false

In ______ casting, molds can be reused.

	1. c,d
a. investment casting	2. c
b. sand casting	3. b,c
c. permanent mold casting	4. a,c
d. die casting	5. all

The different coats of ceramic material making up an investment casting mold are usually of the same general composition.

a. true
b. false

Investment casting is capable of lesser tolerances than most other casting processes.

a. true
b. false

In sand casting, the pattern is removed by melting in a caustic media.

a. true
b. false

In sand casting, the solidified casting is removed by opening the mold.

a. true
b. false

______ can result with improperly applied shrinkage allowances.

a. shrinkage voids
b. cracks
c. non-fill
d. dimensional discrepancies

Casting is generally more precise than forging.

a. true
b. false

Properties are generally better in castings than in forgings.

a. true
b. false

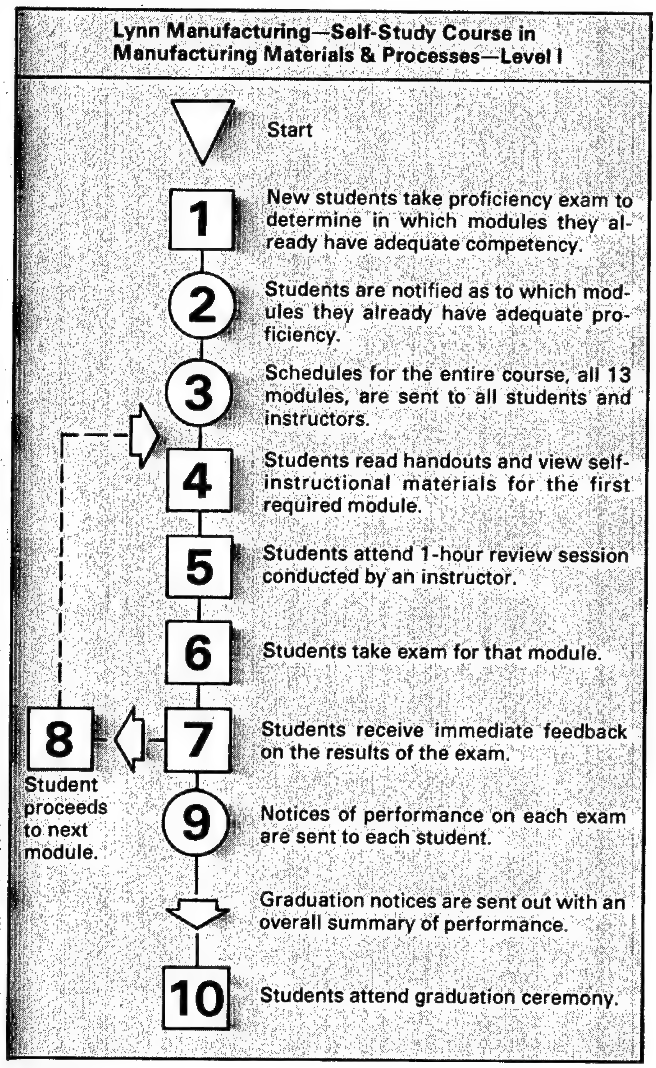


Figure 1

tooling; estimating machine time; equipment; and safety.

- Sheet Metal—covers sheet metal materials, their behavior and technology; typical operating problems; and cost information for shearing, blanking and louvering, bending, drawing, expanding, and spinning.

- Joining—specific to resistance welding, gas tungsten arc welding, brazing, and electron beam welding, this course covers fixtures, fits and tolerances, heat affected zone characteristics, operator requirements, equipment certification and inspection procedures, as well as typical operating problems and the specifics of high-technology joining.

- Quality Control—describes the manufacturing system—its role, implementation, processes, and underlying philosophy—and presents information about the gaging, measurement, nondestructive evaluation, and source substantiation, as well as how product quality interfaces with other organizations.

- Rotating Parts—synthesizes information from the prerequisite courses on conventional metal removal, electrical discharge machining, and numerical control to take students through every step in the planning, production, and trouble shooting of typical rotating parts.

- Fabricated Parts—synthesizes material from the prerequisite courses—sheet metal, joining, and quality control—to take students through every step in the planning, production, and trouble shooting of typical fabricated parts.

- Miscellaneous Processes—provides detailed technical information about heat treating, thermal spray, cleaning, and shot peening.

- Assembly, Inspection, and Testing—covers production planning, production control, assembly techniques, quality methodologies, engine testing procedures, and the logistics of shipping and billing completed engines, emphasizing how these functions interrelate to make the production system work.

Approximately 650 employees have taken the LII program so far. Although satisfied that this extensive program has gone a long way toward meeting the needs identified in 1977, G.E. is constantly seeking to improve existing courses and broaden the overall scope. Present thrusts are toward familiarization with CAD/CAM Microprocessors, their operation and capabilities, and toward training of the hourly work force.

Training for the Real World

Tech Program Stresses Practical Skills

ROBERT E. WALLENTINE is Head of the Manufacturing Engineering Technology Department at Weber State College, Ogden, Utah. Besides his administrative duties he teaches Hydraulics and Pneumatics, Engineering Mechanics, Production Control, and Manufacturing Planning. Since receiving his M.S. Degree in Manufacturing Engineering from Utah State University in 1970, Mr. Wallentine has devoted much of his time at Weber State College developing innovative curriculum and writing individualized skill modules. He joined the faculty at Weber State in 1963 after receiving his B.S. Degree in Tool Engineering from Utah State University and working at Aberdeen Proving Ground for the U.S. Army Ordnance Corps, Lawrence Radiation Laboratory in Livermore, California, and Thiokol Chemical Corp. at Brigham City, Utah. His area of specialty with Thiokol and Lawrence-Livermore was tool engineering. Mr. Wallentine has conducted extensive studies on wear-out rates of aircraft components and specialized tooling for the nuclear and missile industries, and during the course of his assignments has also participated in training courses in quality control, production control, and engineering fundamentals for inplant employees.

In hiring manufacturing personnel, industrial companies are placing high priority on students who already have manufacturing knowledge, experience, and skills—employees they can put to work immediately without 6 months or a year of in-plant training and orientation to the real world. Weber State College's 4-year B.S. program in Manufacturing Engineering Technology (MET) provides preemployment manufacturing training that prepares students to meet this need.

The Weber State program stresses broad practical knowledge and skills rather than a research orientation. It is designed to produce graduates who can apply current manufacturing technology to effectively and efficiently produce manufactured parts. These people are trained to prepare processing plants; select machines, tooling, and inspection methods; and write the processing instructions needed to implement the plans. Since its inception in 1964, the program has achieved 100 percent student placement. At present, Weber State graduates 25 to 30 students each year.

In addition to the B.S. in MET, the MET Department at Weber State offers a B.S. in management logistics, an associate of applied science degree (2 years) in manufacturing technology, and 1 and 2 year programs in machine tools, welding, engineering graphics, and carpentry.

Simulates Real World

A primary reason that the program can supply what industry needs is that it operates in an environment as close to the real working world as academic situations allow. The preemployment training program provides practical experience in planning and producing manufactured products. Furthermore, it emphasizes human relations, communications, and management skills, integrating the use of these skills into the manufacturing process. How is all this done?

There is more involved than is evident by just looking at the curriculum (Figure 1). Through their first 3 years, students gain practical knowledge in different areas of manufacturing—assembly and fabrication operations, tool fabrication, tool design, part design, manufacturing methods and layout—by actual hands-on work in addition to classroom work. The knowledge and skills developed

NOTE: This article has been based on a paper presented at the 12th Annual Conference of the Manufacturiong Technology Advisory Group in Miami Beach, at which a special forum was held on academic programs involved with new MT.

MANUFACTURING ENGINEERING TECHNOLOGY					
BACHELOR OR SCIENCE DEGREE (4 years — 202 credit hours)					
		FRESHMAN			
Autumn		Winter		Spring	
RELTE 114	5	RELTE 115	5	RELTE 117	5
ENGTC 236	5	MCHTL 102	1	MFENT 123	3
MCHTL 100	1	MCHTL 103	2	MFENT 132	3
MCHTL 101	2	DATPR 101	4	COMUN 102 or	3
ENGTC 142	4	INENT 142	3	COMUN 105	
ENGLI 101A	1	ENGLI 101B	1	ENGLI 101C	1
	18	PHYED	1	DATPR 260	3
			17		18
		SOPHOMORE			
Autumn		Winter		Spring	
RELTE 118	6	ENGTC 244	3	ENGRG 245	3
MFENT 231	2	MFENT 232	2	INENT 350	4
MFENT 244	3	MCHTL 202	1	ENGTC 332	3
INENT 353	2	MCHTL 203	2	ENGTC 334	3
ENGTC 330	5	CHEM 101	5	WELDG 360	3
PHYED	1	ENGTC 331	4	HEALTH	2
	18		17		18
		JUNIOR			
Autumn		Winter		Spring	
PHYS 111,114	5	MFENT 302	3	PHYS 113,116	5
MFENT 301	3	ENGTC 355	3	ENGTC 456	3
MFENT 331	3	ELTCH 136	5	INENT 351	3
ELTCH 124	5	ELTCH 137	2	HISTY SS170	5
ENGLI 102	3	ENGTC 345	3	PHYED	1
	19		16		17
		SENIOR			
Autumn		Winter		Spring	
ENGTC 461	2	ENGTC 462	2	ENGTC 463	2
INENT 401	3	ENGLI 103	3	MFENT 499	2
MFENT 452	2	*General ED(2)	6-9	*GENERAL ED(2)	6-9
ECON 101	5	Electives	3	Electives	3
*GENERAL ED(1)	3-5	**HU or SS	3		13
	15		17		
*General Education courses must be selected from Life Science (9 cr. hrs.) and Humanities (9 cr. hrs. — one course must be literature. Other requirements are met in the core. **Additional requirement of ECPD accreditation.					
Suggested Electives:	MFENT 246 (3)	INENT 342 (3)			
	MFENT 492 (1-6)	INENT 360 (3)			
	ENGTC (3)	INENT 458 (3)			
	AUENT 420 (3)				

Figure 1

are all brought together during the final year with a senior project.

The senior students in MET, with some faculty input and under certain budget restraints, select an industrial product, plan the manufacturing process for it, and then actually produce it. The facilities available to the students to accomplish this include computer graphics system, terminal access to a computer with numerical control programming capability, numerical control machines, a machine shop and foundry, plastic injection molding equipment, hot stamping machines, vacuforming machines, and inspection, metal forming, welding, drafting, heat treating, and hydraulic labs.

In completing the project, the student must conduct a design study of the product drawing, including building of a prototype; prepare a project schedule and operations process sheets; complete time and cost estimates to ensure the most economical process; coordinate tool and equipment design; plan assembly methods and in-process material handling; coordinate production layouts; prepare detailed inspection specifications; and complete a detailed production control plan to include manhours needed for each operation.

Stresses Communication Skills

As noted, a very specific aim of the manufacturing planning experience is to develop student expertise in human relations, communications, and management skills. At the end of each quarter, senior students report their progress and defend their work before the MET

department faculty. This gives the student simulated experience in "selling" ideas to management. At the same time, the faculty can evaluate student progress and give new direction if necessary. In addition, there are several other steps in the planning and production process during which students develop important communication and management skills while they gain production knowledge.

For example, each student must telephone, personally contact, or correspond with sales or manufacturing firms to get bids on items such as standard parts, subcontracted manufactured parts, tooling, and equipment. It often takes considerable skill to get a vendor to bid on a job that offers little financial reward.

Each senior also must deal directly with junior MET students in tool design to communicate what the tools must do. The seniors must also assure themselves that the tools will perform economically and maintain the required part tolerance during the production run.

After signing off on tool design drawings, the manufacturing student takes them to the tool builder (sophomore MET students or second year students in the machine tool program). Once again, the senior must effectively communicate the tool concept and must follow tool fabrication to assure that each tool is built to specifications. The senior must also select and order the materials necessary to construct the tooling and oversee any required modifications after a trial run of the tool.

When satisfactory tooling is ready, the senior schedules a pre-production run and takes the tooling and raw materials to freshmen students who build from 1 to 50 parts to verify accuracy of the process and tooling. When casting or other processes with which freshmen are not familiar are required, the seniors may produce their own parts.

The culmination of the student's effort in developing a manufacturing process is assembly of the senior project. Depending on the project, one or more students may be assigned to design and tool up for assembly. Students take their parts from the manufacturing process and systematically assemble them according to the process outlined in their assembly charts and methods. As assembly or production problems are encountered, the students must solve them.

Encourages Cooperation

Wanting to improve on the product and the efficiency of the previous year's group, the students develop new methods to motivate tool designers, tool builders, and others involved in the production process. The group generally becomes very cohesive, learning to work together and to support each other as the students become concerned about the needs and goals of others and try to help each other meet these goals. This brings home the importance of organizational support in a manufacturing operation.

After completing this project, the Weber State College MET student graduates with broad knowledge and effective skills in manufacturing technology. Judging from the 100 percent employment of MET graduates and their on-the-job successes, it is apparent that both industry and students have much to gain from highly articulated, well-developed preemployment manufacturing training such as that provided at Weber State.

Firm Shop Data on Time

Automated Reporting Makes Workload Easier

By
D. R. Ippolito
Project Engineer
Watervliet Arsenal

How can shop data from Monday afternoon production be used when it's not available until Friday morning? — Certainly, it would be difficult to use in planning shop activities on Tuesday, Wednesday, and Thursday. Neither would it be too usable for Friday production, which would have to be scheduled earlier than Friday morning. This dilemma was the motivating factor that caused the U.S. Army Armament Material Readiness Command to initiate a major manufacturing technology project at Watervliet Arsenal's cannon production facilities. The goal was to realize "Improved Manufacturing Control Through Data Automation", which was achieved upon completion of the project in June 1979.

At Watervliet Arsenal, the Production Control Activities exercise coordination of facilities to produce cannons on schedule and at optimum cost. While the Watervliet Arsenal had continued to be the worldwide leader in cannon manufacturing technology, the development of advanced production control systems had not kept pace with advancements in manufacturing technology. The manual production control systems in use before this project was begun were not sufficiently responsive to the constantly changing workload environment; they did not permit the best use of the high productivity and economy of production offered by modern manufacturing methods and equipment. Management and financial reports from the manual system were being provided as late as three days after work had been performed. The weaknesses of the manual reporting system were concentrated in the areas of labor reporting. Planning, forecasting, scheduling, material control, and machine loading were very difficult and very time consuming. The problem required modernization of Production Control Systems by using data automation techniques to realize the full economic benefits of new manufacturing technology.

NOTE: This manufacturing technology project that was conducted by Watervliet Arsenal was funded by the U.S. Army Armament Materiel Readiness Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The ARRCOM Point of Contact is Mr. T. M. Wright (518) 266-4231.

Source Data Collection

The basic objective of this undertaking was to establish a Production Automated Control System (PACS) which would facilitate planning, workload forecasting, short and long range scheduling, material control, and machine loading. All production data needed to be collected, processed, and fed back to users within 24 hours. This was the optimal requirement which would not only reduce planning and production lead times but would also increase productivity and utilization of resources.

An automated shop data collection (SDC) system was introduced into the manufacturing complex at the Watervliet Arsenal. The core of this system is made up of 42 remote

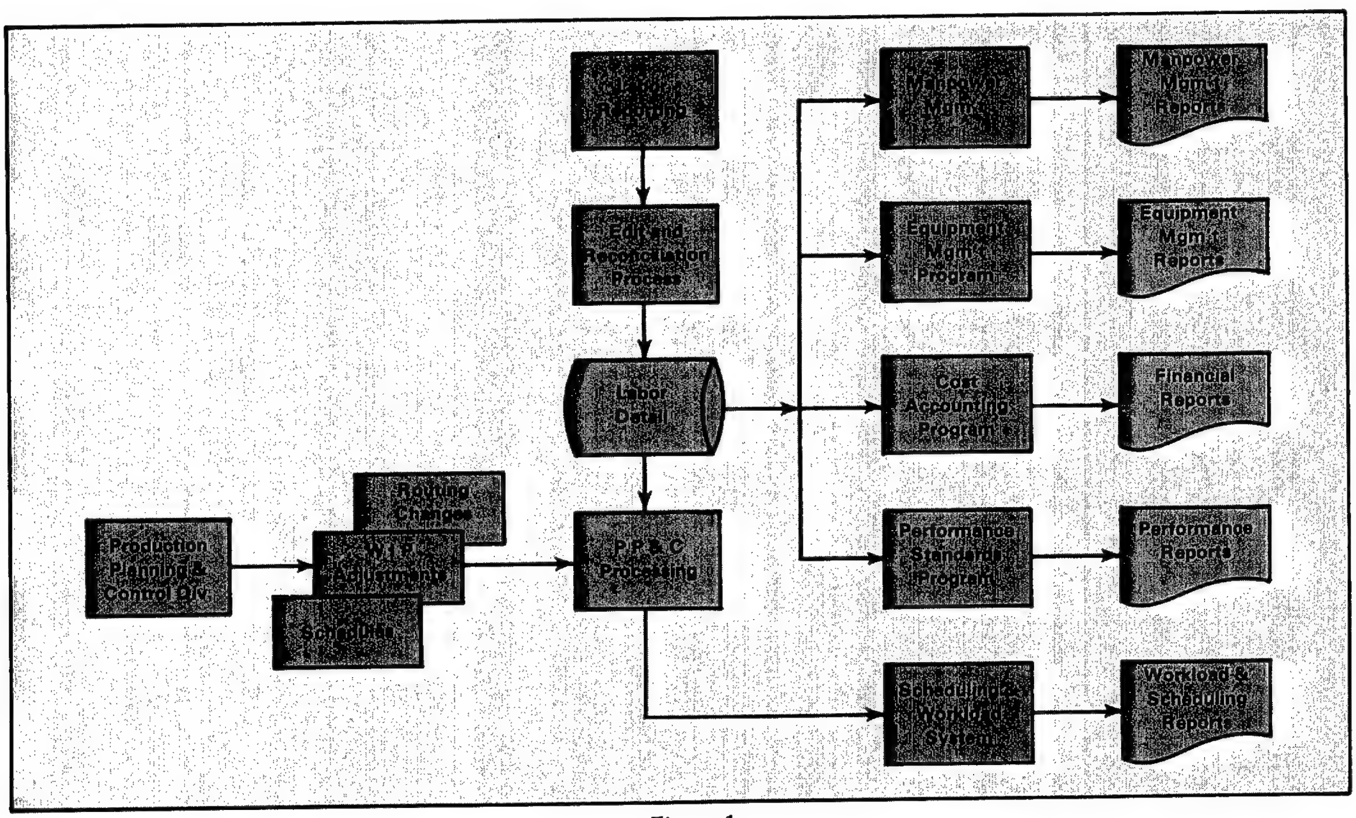


Figure 1

data entry terminals which are located in the six major manufacturing departments and approximately 25 costing areas that collect shop data. All production is reported daily by shop labor through the SDC system. This labor reporting system drives the entire Production and Financial Management System at the Arsenal. Figure 1 shows the processes involved in this automated system.

Data Reported Overnight

Through the use of SDC, feedback reflecting the previous day's progress, problems, and performance is furnished to shop managers by 7:30 a.m. each day. Turnaround time has been reduced from three days to one day. By receipt of accurate and timely information, shop supervision is more responsive to problem solving, and substantially less effort is devoted to correcting reporting errors. As of March 1979, shop efficiencies averaged 92.2 percent, an increase over the base year (1972) of 3.9 percent. This increased production would have required 30 more direct labor personnel under 1972 conditions.

Obviously, the isolation of the productivity increase which can be attributed to this project cannot be fully quantified since other management actions dealing with more efficient plant arrangement, workload mix methods improvements, and other factors also contribute. However, it is estimated that a full 1 percent productivity increase is appropriate for association with this project — or a cost benefit of approximately $150,000. This figure is equivalent to 7.5 man-years of direct labor.

The SDC system also has resulted in a more efficient and timely reconciliation of job cost versus payroll cost. This aspect previously presented serious control problems within the cost accounting function. The management goal of less than 50 weekly exceptions has been achieved, and for the first time on record, has continued below target. In turn, this has resulted in increased confidence in the integrity of the data base.

Control System Precludes Duplicate Records

The basic software of the Production Planning and Control (PP & C) computer data base incorporates the use of IBM's Chain File Management System (CFMS). Through the use of Chain File programming techniques, Bills of Material can be exploded for all component part requirements. Simultaneously, the manufacturing route sheet data base may be accessed for (1) computing manufacturing cost estimates and (2) generating purchase requests complete with specifications for production materials.

Therefore, the data base master files are used for computer generated cost estimating, cost accounting, labor and workload forecasting, production scheduling, machine loading, bills of material processing, automatic generation of the procurement request for production material, and associated stores issue tickets. The use of common data base files has eliminated departments maintaining their own sometimes inconsistent duplicate files.

The results of this project effort confirm the validity of the premise that mechanized source data collection is a prerequisite for improved manufacturing control. It also has demonstrated the high potential for improving manufacturing control and productivity through data automation.

Increased Capability-Reduced Size

Transcalent Transistor Dissipates Heat Faster

FREDERICK G. PERKINS serves as the Development Project Officer for the Power Conditioner program at the U.S. Army Mobility Equipment R&D Command. He was assigned to the Command's Electrical Equipment Division in 1978 after five years as Staff Engineer to the MERADCOM Project Officer for the Patriot missile system. Formally educated as a chemical/electrical engineer, Mr. Perkins is a Registered Professional Engineer with 17 years of experience in industrial battery research and related electronics industries. Before joining the Government service in 1965, he was a Project Engineer for the .3 kW fuel cell power source, for which he was team leader during contract evaluation of the power source in Vietnam. Mr. Perkins then served as technical representative to Project MASSTER and TRICAP exercises. He received his bachelor's degree in Project Management from the Defense System Management College and also has received degrees in accounting and business administration.

Photograph

Unavailable

Under a contract from the Army's Mobility Equipment Research and Development Command in cooperation with the Navy, RCA's Electro Optics and Devices Division has developed a new family of high power semiconductor switches which use a unique method for dissipating heat. Whereas conventional semiconductor switches use large heat sinks with fins to conduct the heat to an outside air stream and their bulk is a hindrance to clean design and small size (Figure 1), the new RCA transistors use heat pipes and transcalence (permeability to heat flow) to dissipate heat.

Heat pipes (Figure 2) make use of the large heat absorbing capacity of an evaporating fluid. Water or freon is fed to the heated surface where it evaporates and cools the area; vapor then is conducted to a cooler area where it condenses and is returned by capillary action to repeat the cycle. This can be done in a heat pipe with porous copper wicking, requiring no moving parts. This type of heat pipe has an effective thermal conductivity several times greater than copper.

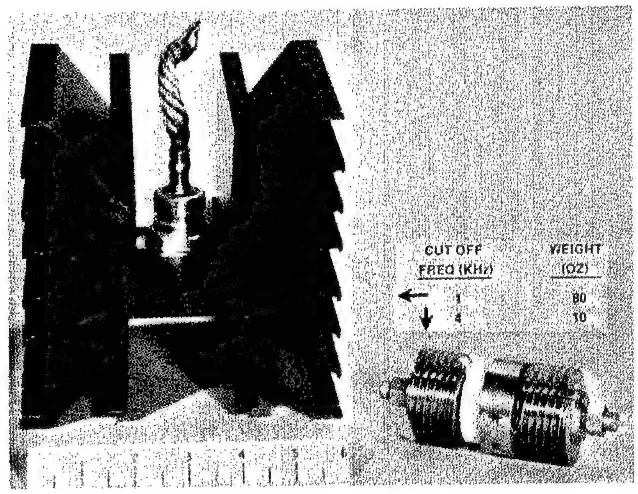


Figure 1

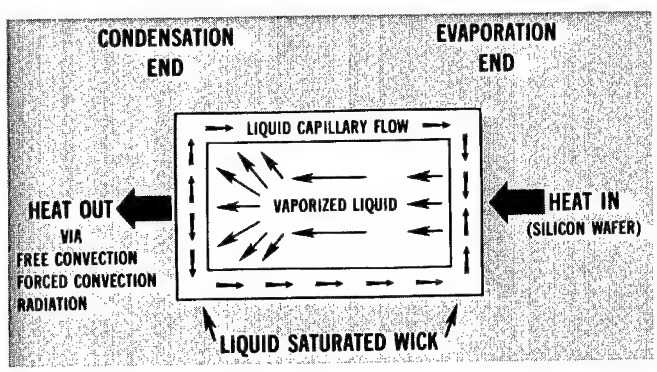


Figure 2

Production Engineering Required

RCA developed specialized fixtures and procedures for rapidly fabricating the heat pipes and for bonding the bases of the two heat pipes to opposite sides of a silicon transistor wafer. High temperature brazing of the heat pipe body, sintering of porous wicks, and ceramic to metal sealing were production engineered to permit volume manufacture. Plating, lapping, and soldering methods were tailored to obtain blister free, void free metal joints between the heat pipes and the transistor wafer.

Each heat pipe consists of a molybdenum disc in contact with the silicon transistor wafer, a cylindrical porous copper body which serves as the wick, and a copper end closure and spiral fin assembly that forms the outside walls (Figure 3). This particular transcalent transistor weighs ten ounces and is five inches long and two and a quarter inches in diameter; it is a 100 A, 750 V, 500 W· dissipation transistor.

NOTE: This manufacturing technology project that was conducted by RCA was funded by the U.S. Army Mobility Equipment R&D Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The MERADCOM Project Engineer is Mr. Frederic Perkins (703) 664-5724.

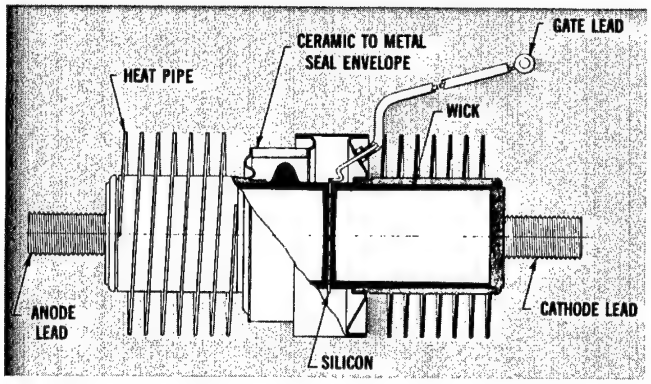


Figure 3

Current Sharing Precludes Overheating

While the transcalent transistor was being designed, it was decided that the diameter of the emitter should be limited so that the majority of the heat loss in the silicon would be dissipated by the heat pipe. The transistor wafer has 72 separate emitter fingers diffused into its base. In effect, it consists of 72 transistors arrayed radially, extending from the center of the chip toward the outer edge. If the current is not shared equally and only a few of the emitters are conducting, a small area of the wafer may overheat and thermal runaway can occur. To make sure that current sharing occurs, a second silicon wafer—called a ballast resistor—was added to the transcalent transistor package. This particular design (Figure 4) was chosen because it provides easier maintenance, more reliable operation, and simpler production. The effect of the ballast resistor is to limit current flow to individual emitters and thus force current sharing.

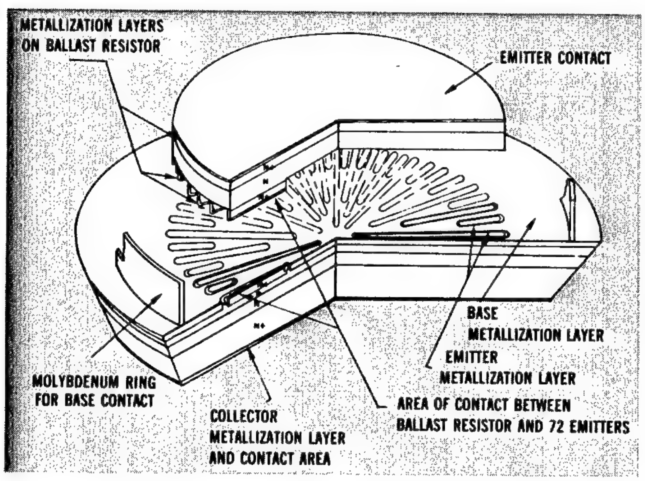


Figure 4

Greater Tolerance, More Stability

Unlike the conventional stud mounted "hockey puck" (TO-3) transistors, no external mechanical clamps are needed to fasten the transcalent transistor to the heat sink. Thus, installation of the device is not a problem. Also, there is no relaxation of the clamping force due to creep of copper or aluminum parts which might result in inadequate cooling and poor electrical contacts. In addition, the assembly has a high resistance to fatigue failure since the materials adjacent to the silicon and bonded to it either nearly match the thermal expansion of the silicon or are designed to yield elastically.

In operation, this device is very tolerant to changes in power level without current derating because the heat pipes respond quickly by evaporating an additional amount of working fluid. Only a small increase in junction temperature results when the device is operated under overload conditions. The ceramic insulator length itself is thus very adequate for high voltages, even at higher elevations.

Civilian Applications Wide Ranging

The light weight of transcalent transistors and their **high strength to weight ratio** make them ideal for military power conditioners which are deployed in the field. Since the right power source is not always available at the right time, conditioners are needed to convert the quality, voltage, frequency, and/or number of phases generated to the type required. **Easy maintenance** is another definite advantage.

Although the transcalent transistor was designed with military use in mind, the possible commercial uses are also quite diverse. Transcalent transistors can be used for electrochemical plating and metal refining, induction heating, and power distribution load leveling. They also would be applicable for motor speed control, vehicular drives, and welding control. In essence, the transcalent semiconductor can be invaluable for any utilization requiring substantial electrical power.

73% Cost Savings

Antenna Design Simplified

GUY F. ORIGLIO is a Project Officer with the U.S. Army Mobility Equipment Research & Development Command at Fort Belvoir, Va., where for the past 20 years he has worked on the Army's electronics devices. He has had extensive experience in research on detection systems such as the METRRA system and has worked on Army radar research and development, both ground based and airborne, particularly that which is suited for defining high value targets such as tanks and other mobile equipment. Mr. Origlio received his B.S. in Physics from Pennsylvania University in 1953 and since has done graduate studies in communications at George Washington University. He is a member of Sigma Xi, the Research Society of America, and the American Physical Society.

Photograph

Unavailable

Since 1971, Cubic Corporation has been working for the U.S. Army Mobility Equipment Research and Development Command to develop a vehicle mounted road mine detector system (VMRMDS) which is capable of detecting buried plastic and metallic antitank mines. The system detects the mines by transmitting radio frequency (RF) signals into the ground then analyzing the return signals reflected from below the surface. The RF signals are transmitted and received through an antenna array in the search head, which is mounted at the front of a search vehicle; the array is made up of ten individually articulated antenna modules. As these ten antenna modules are vulnerable to damage from obstructions in their path, they must be low cost and easy to replace in the field.

Production techniques in use at the start of this contract represented a cost of approximately $350 per antenna module. Based on a projected total procurement of 25,000 antenna modules, significant potential savings were foreseen if production costs could be drastically reduced. The existing design requires fabrication from aluminum sheet, which was cut, formed, and fastened to a reflector/septum with screws. Two small brass dipoles were used per assembly as the radiating elements (Figure 1). While strength and electrical performance were satisfactory, a quick analysis revealed that the major cost element is the number of man-hours required to fabricate and assemble the many parts of the antenna assembly. In addition, the all metal construction introduces undesirable tolerance requirements on the various pieces.

Therefore, the critical production item was identified as the reflector/septum. The key to cost effective assembly would be the method used to fabricate the reflector/septum and the ease with which it could be assembled into the antenna assembly. The investigation of production designs included evaluation of metalworking, foaming, fiberglass, and plastic molding techniques.

Rotational Molding Technique Most Feasible

Various metalworking techniques were found to be unacceptable for producing the antenna assembly. Roll forming was rejected on the basis of per unit cost alone, due to the size of the anticipated production run. The major drawbacks to hydroforming are the initial cost of the hydroforming machine and the size of the production run that would be required to make this method economically feasible. Stamping was judged to be adequate, though several disadvantages exist:

- Requirement to apply some form of surface protection to the metal pieces
- Need for multiple handling of the parts during the assembly process
- Possibility of the guards being too lightweight or the reflector/septum too thin.

NOTE: This manufacturing technology project that was conducted by Cubic Corporation was funded by the U.S. Army Mobility Equipment R&D Command under the overall direction of the U.S. Army Directorate of Manufacturing Technology, DARCOM. The MERADCOM Project Engineer is Guy F. Origlio (703) 664-4498.

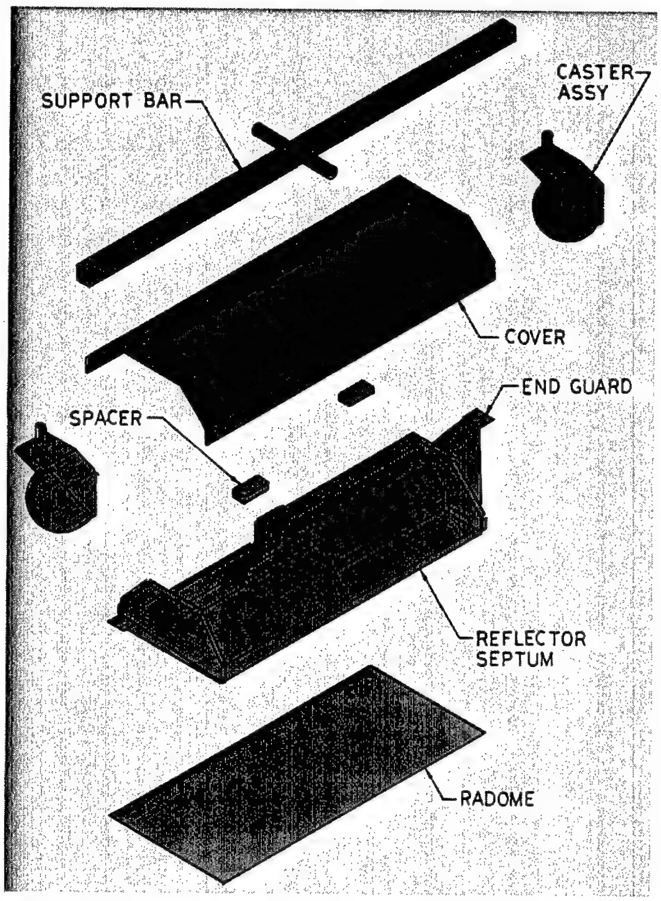


Figure 1

Plastic injection molding was considered, but it too was rejected because of an uncontrollable amount of warpage that can be expected in a part of the size of the antenna assembly. In fiberglass fabrication methods, the fiberglass material can vary considerably from part to part and within an individual part itself; this thereby decreases the overall life and reliability of the assembly. A foam in place concept was eliminated because of the high cost of the foam and the marginal weight of a completed cover/reflector/septum assembly.

Rotational molding of the assembly was considered to be the best production method overall. Here, the cover, guards, and support bar are incorporated into one molded polyethylene plastic piece with aluminum inserts used to reinforce the plastic in the crossbar and caster assembly areas. There are numerous advantages to this production method: incorporation of the support bar decreases the number of parts and fasteners required; there is no weight problem; painting is not required; after the molding process, no close tolerance work is required by outside vendors, thereby reducing the rejection rate. Finally, an almost entirely modular construction reduces the logistics problems downstream. The polyethylene material selected was Marlex CL-100 produced by the Phillips Petroleum Company.

Superplastic Metal Thermoforming More Reliable

Although standard plastic thermoforming and metal drophammer production methods were considered for fabricating the reflector/septum, superplastic metal thermoforming was judged to be more useful. In this process, two different superplastic metals were considered. One was approximately 78% zinc and 22% aluminum. The other was primarily aluminum with only a small percentage of zinc. These metals are unique because at process temperatures they soften and take on the formability of thermoplastics. Thus, using techniques similar to the vacuum forming of plastics, sheet material can be formed into complex and intricate shapes in one operation on a single low cost tool (Figure 2).

There are certain advantages to the use of the primarily aluminum alloy as compared to the primarily zinc alloy. The zinc alloy exhibits a tendency toward brittleness and, once formed, cannot be bent readily. In contrast, the aluminum alloy can be bent and formed without the danger of brittle cracking, but it requires more liberal edge radii at the bends. While investigation still is continuing in this area to determine the most desirable material, the process itself still appears to be the most desirable for use in the fabrication of the reflector/septum.

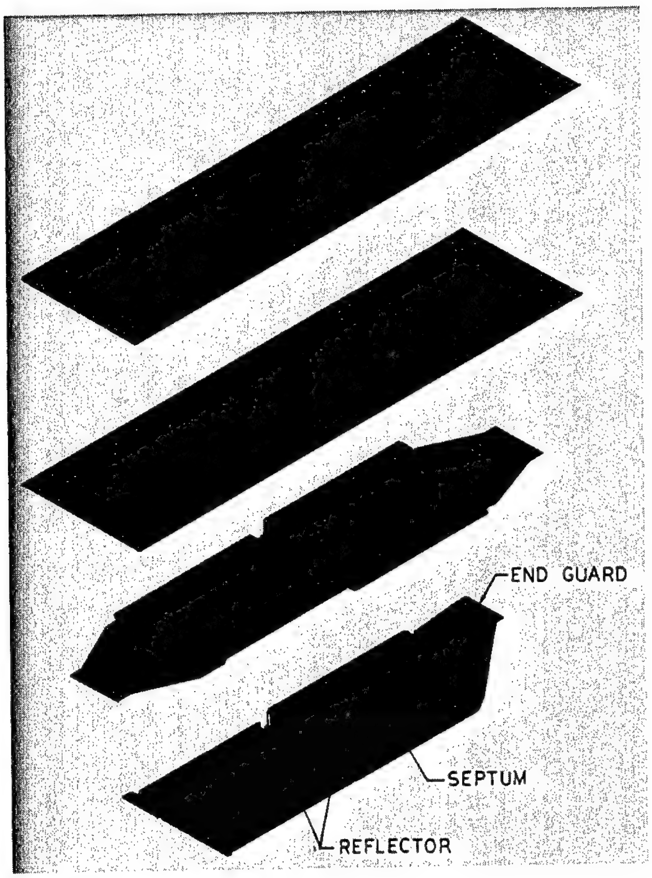


Figure 2

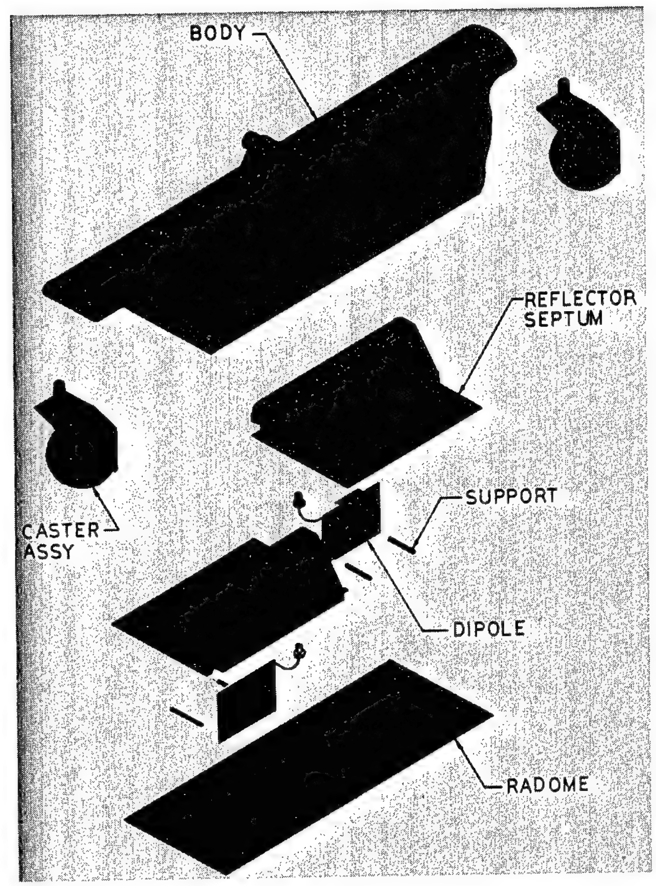


Figure 3

Final VMRMDS Assembly Recommendations

There are several advantages to the antenna module manufacturing techniques recommended that make the selected configuration (Figure 3) an excellent choice for use on the VMRMDS. The component parts count is minimized with the one piece rotational molded body. This greatly reduces assembly labor time and machine tolerance requirements that existed with the current antenna assembly (several metal pieces which had to be bolted or riveted together). The weight of the module easily is within the desired range. In this method no extra weatherproofing protection is required. Further, the design is inherently waterproof and the materials used do not require any painting or chemical protection. Due to the small number of parts, assembly can be performed quickly and easily, and the number of rejected parts is expected to be low. Finally, the cost of this mechanically sound and highly reliable module is only $95 compared to $350 for the original model.

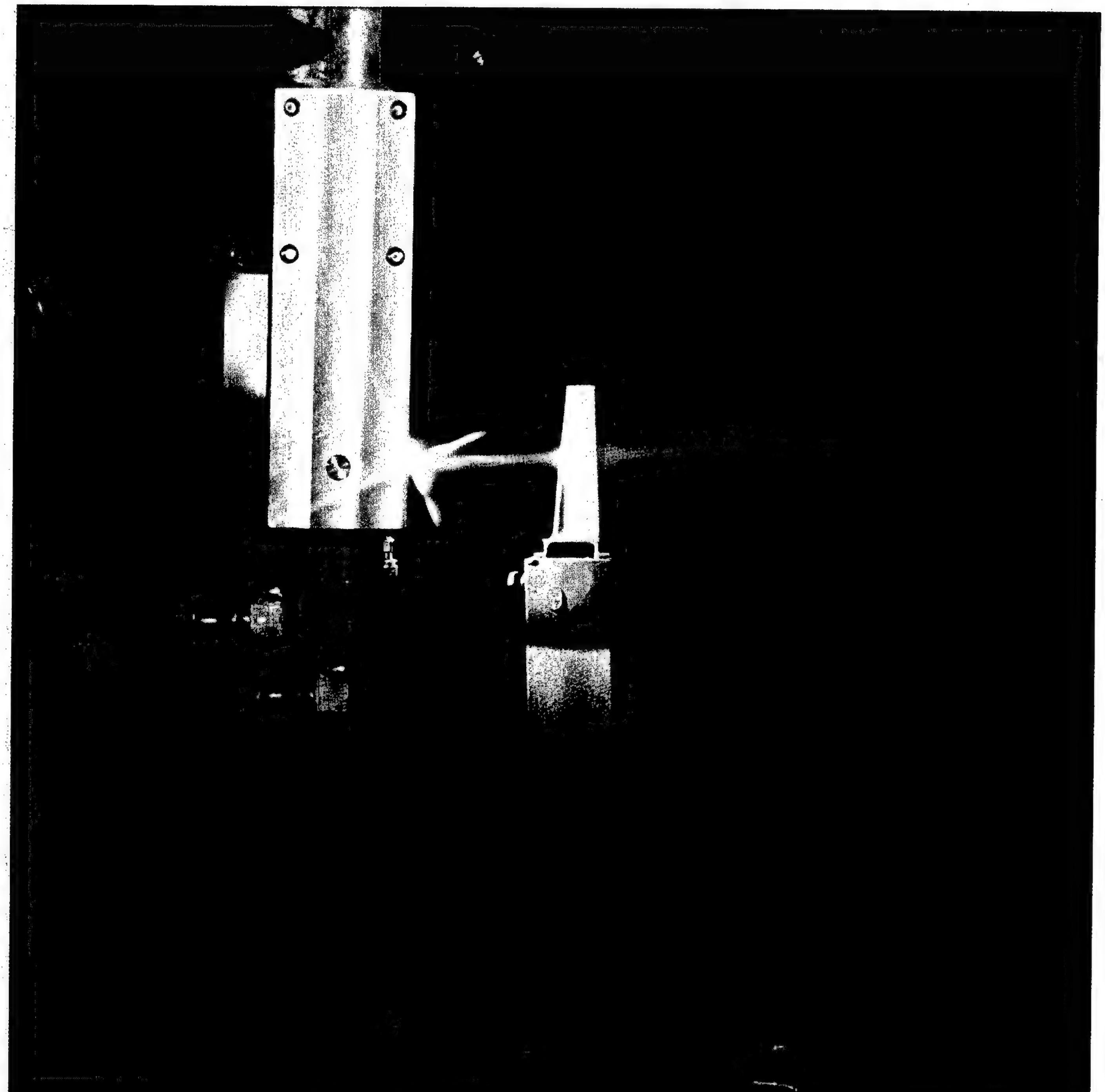
In view of the many advantages listed above, it appears that the recommended antenna module production technique should prove to be an effective and reliable method for achieving the goals set forth at the beginning of this study.

US Army

ManTech Journal

Prepared to Respond

Volume 7/Number 1/1982



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Volume 7/Number 1/1982

Contents

1 **Comments by the Editor**

2 **Isothermal Forging For T53 Impellers**

10 **Fuel Aromatics' Degradation of Rubber**

16 **Projectiles Targeted Acoustically**

19 **Preventing Plated Through Hole Cracking**

26 **Disposable Mandrels for Making Rocket Motors**

34 **MM&T of Large Scale Hybrid Microcircuits**

44 **Brief Status Reports**

Inside Back Cover — Upcoming Events

About the Cover

The photograph on the cover of this issue shows an aircraft engine high pressure turbine airfoil being plasma spray coated with a thermal barrier coating which provides a protection against high temperature degradation of the airfoil base material. Deposition is being accomplished with a computer controlled plasma spray system that was developed by Battelle's Columbus Laboratories for the U.S. Air Force during a manufacturing technology program. The system presently is being used by Avco Lycoming to coat components of the turbine engines for the Army's XM1 tank at Stratford, Connecticut. It has the capability of providing self-compensating control of all the plasma spray processing parameters, including the class loop control of five axes of spray head manipulation. This control of the process permits uniform coating of complex shapes such as the airfoil shown.

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Comments by the Editor


RAYMOND L. FARROW

World events continue to remind those of us in the materiel readiness field that a nation has little time for long range planning when suddenly confronted by an adversary. The nations of the Free World must be prepared at all times to respond to such an event; any such reaction also entails fearful logistic challenges. Our long term mantech efforts will be called upon to meet these logistic challenges when they occur and the nation is forced to mobilize its production. Hoping that this is not going to happen is perhaps unrealistic in review of past history. Personnel engaged in these mantech efforts must always keep in mind that the project on which they are currently working could provide a crucial advantage during a time of crisis. We could at that time have to marshal our production capabilities to replace heavy early losses resulting from such a confrontation. The past nearly two decades of Army MT work will play a critical role in meeting the challenges that may lie ahead.

This first 1982 issue of the U.S. Army ManTech Journal contains articles of widely different content—all reflecting a dramatic improvement in some manufacturing technique. A joint project by the U.S. Army Aviation R&D Command and the U.S. Army Materials and Mechanics Research Center involved first a forging study by IIT Research Institute and then a specific hardware program by Avco Lycoming. The study developed a practical new means for isothermally forging impellers for the T53 turbine engine built by Avco Lycoming for use in the Army's helicopters. Such a multiple interface program required unusual administrative skill and cooperation, and it must be commended.

Engineers at the U.S. Army Mobility Equipment R&D Command in Ft. Belvoir have developed some useful information about the inconsistencies of commercial fuels. Attendant problems limit their potential for determining deterioration rates in rubber exposed to them.

Acoustic target scoring of test round firings at U.S. Army ammunition plants is a remarkable development of the Ware Simulation Section at Rock Island Arsenal, as described in our third article of this issue. During a full scale production requirement, this device alone could revolutionize quality controls on production ammunition.

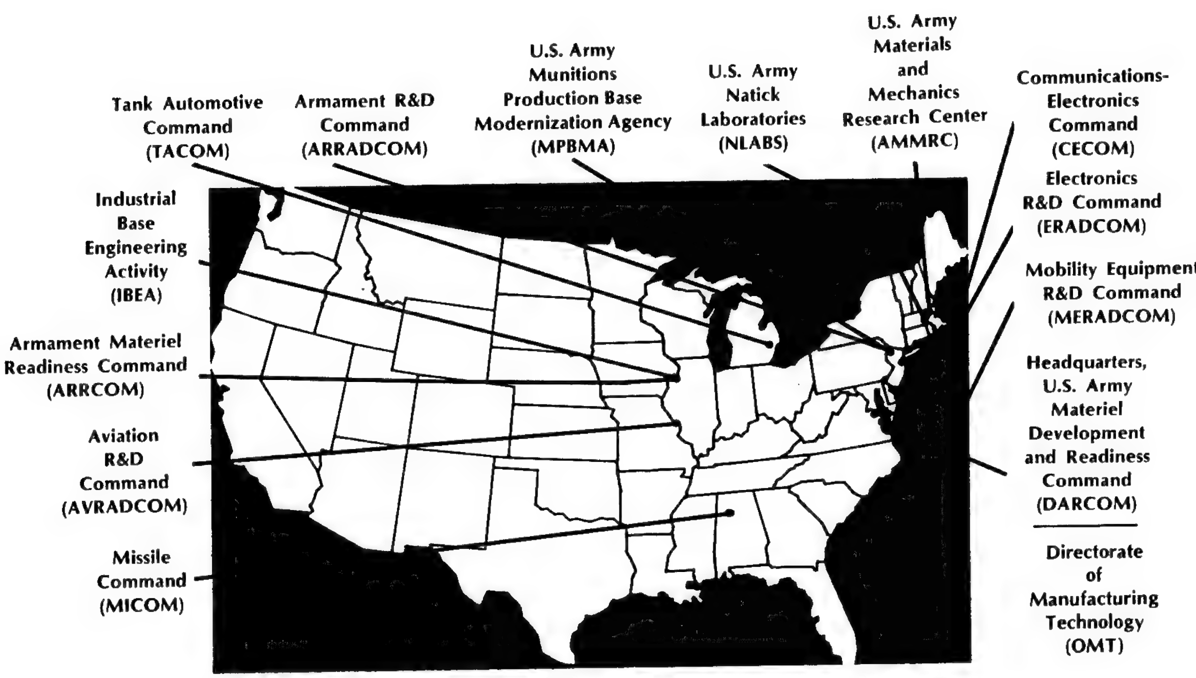
A long time friend of the Army ManTech Journal, Lloyd Woodham of MICOM, is the author of an interesting article on Page 19 of this issue, in which he sums up the results of a mantech project to eliminate cracking of the copper plating in the plated through hole of multilayer boards. The project findings of the high reliability of polyimide-glass in this process will resolve problems that have been plaguing designers for years.

The most opportune time to use a new method for producing disposable plastic mandrels was an important finding in another mantech project discussed on Page 26. This project funded by the U.S. Army Missile Command produced results typical of many Army mantech projects. It not only developed a feasible new method for manufacturing an item, but it also pinpointed when it was not best suited for economical production.

An important achievement in fabrication of large scale hybrid microcircuits is discussed in the last article in this issue, which describes new manufacturing methods and technology for producing components that will withstand missile launch environments, though possibly not cannon launch conditions. This Missile Command project introduced methods that will achieve 30 percent cost savings.

Again, we feature a large number of briefs of ongoing projects in the last pages of this issue, since we have received a generally universal request from our readers for more of these up to date items.

DARCOM Manufacturing Methods and Technology Community



Feasible for Higher Production Rate

Isothermal Forging For T53 Impellers

ERNEST N. KINAS is a Mechanical Engineer, Prototype Development Division, Metals and Ceramics Laboratory, U.S. Army Materials and Mechanics Research Center. He has been active for over twenty-five years in metals research and development, specializing in process development and prototype processing. He is also extensively engaged in engineering investigation programs in high density kinetic energy armor piercing penetrator materials, atomic shell munitions, prototype ceramic forging dies, and prototype high strength metal-plastic laminates. He serves as a forging consultant to other Army organizations and represents the Army in Government committees and conferences on forging. He is a registered Professional Engineer and a member of American Society for Metals, the Project Management Institute, and the American Association for the Advancement of Science. He received his B.S. in Engineering from Northeastern University.

Isothermal forging of turbine impellers is a more costly technique than conventional forging, but it can save overall from less use of costly material and also less machining time. Tooling costs, however, require a longer production run than planned presently for the Army's T53 tank engine before this superior manufacturing technology would prove feasible.

Advanced fabrication techniques have received increased attention because of their potential to reduce the costs of turbine engine components. Isothermal forging is such a technique; its primary advantage is its ability to produce a near net shape and thereby improve material utilization. A program to investigate the potential of isothermal forging to produce a Ti-6Al-4V alloy impeller for the T53 recently has been completed by Avco Lycoming, manufacturer of the Army's T53 tank turbine engine, for the U. S. Army Aviation Systems Command in cooperation with the U. S. Army Materials and Mechanics Research Center. The actual forging study was conducted by IIT Research Institute in an earlier separate program.

The program objective was to produce an impeller forging requiring a minimum of machining. In the IITRI program, several forgings with partial vane channels were produced. One of these forgings (Figure 1) weighs 22.5 lbs compared to the conventional forging weight of 37.5 lbs and the finished part weight of 11.45 lbs. In this case, isothermal forging has reduced the amount of metal to be removed by about 50 percent.

The purpose of the Avco Lycoming program was to further evaluate the isothermal forgings from the IITRI program to (1) investigate their quality, (2) determine critical mechanical properties, and (3) assess the cost savings potential of the near net shape forging by machining a finished component using existing facilities. In

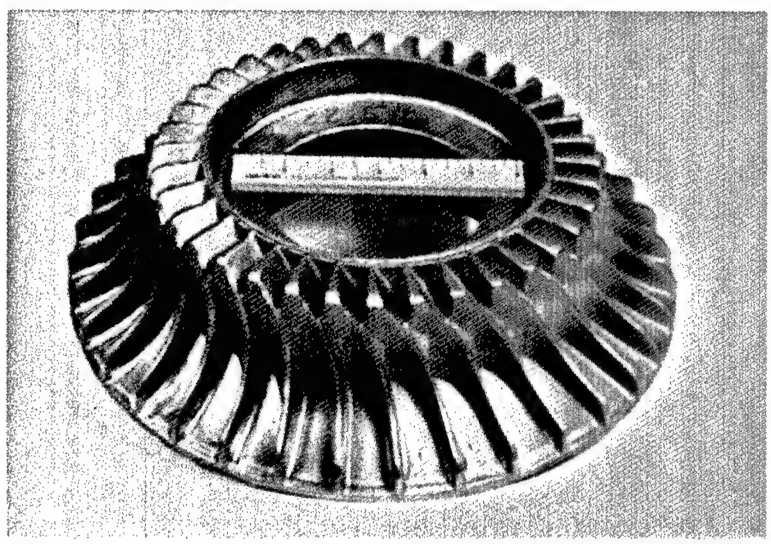


Figure 1

NOTE: This manufacturing technology project that was conducted by Avco Lycoming was funded by the U. S. Army Aviation R & D Command through the Army Materials and Mechanics Research Center under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The AMMRC Point of Contact for more information is Mr. E. N. Kinas, (617) 923-5526.

addition, cost savings were projected for the machining of an isothermal forging using optimized facilities (e.g., advanced numerical control machining techniques).

Quality—Yes; Cost Savings—Possibly

From the results of this program, it was found that:

1. The quality and metallurgical characteristics of the isothermal forgings, including mechanical properties, were considered acceptable by comparison with conventional forging requirements.

2. A finished impeller was satisfactorily machined from one of the isothermal forgings with only minor evidence of under fill. This part is considered to be suitable for engine running.

3. The state of art on isothermal forging practices for production parts indicates that the increased cost of isothermal forging will be generally greater than cost savings from reduced input material. Part of the cost savings in machining normally will be required to offset the remainder of the increased cost of isothermal forging.

4. A cost analysis on the use of isothermal forging for the T53 impeller showed only nominal cost benefits primarily due to the already low machining costs for the conventionally forged and machined part.

5. Based on the above considerations, it is recommended that similar analyses be conducted on other titanium components where the ratio of rough machine costs to final part cost is high. It is further recommended that activity be funded to productionize isothermal forging for those components which can demonstrate a cost reduction.

Forging Evaluations Foresee Problems

Three forgings supplied by the Army Mechanics and Materials Research Center (AMMRC) were first evaluated nondestructively. This evaluation included visual and fluorescent penetrant checks for surface flaws and an ultrasonic inspection for internal defects within limitations imposed by the shape of the forging. The forging judged most sound was dimensionally inspected to ascertain if sufficient material stock existed for a finish machined part. A metallographic evaluation and chemical analysis were conducted on one of the forgings designated for cutup.

Tensile and notch rupture tests were conducted on another forging in accordance with Lycoming Specification M3403 for Ti-6A1-4V in the solution treated plus aged condition. Low cycle fatigue (LCF) and high cycle fatigue (HCF) properties were also evaluated, as these properties are generally limiting factors in an impeller's design and service life.

A finish machined forging was produced to evaluate the forging's cost reduction potential. This machining utilized the current production process whenever possible. The operations were monitored to determine applicability to an optimized production procedure and to reveal any unforeseen machining problems associated with the forging configuration. This information as well as projections on the effects of advanced machining techniques were considered in the final cost analysis. A flow diagram of the program is given in Figure 2.

Billet Edge Chamfer Critical

Visual inspection of forging S/N 10 showed laps in the vanes and on the underface. Fluorescent penetrant inspection showed these laps to have a significant depth and were not likely to clean up on machining. This forging was designated for cutup.

Forging S/N 6 shown in Figure 1 was found to have a chamfer on the major OD as well as incomplete fill of vanes both top and bottom. In addition, laps were present on the inner bolting flange. Zyglo inspection confirmed these observations; however, lap depth was indicated to be relatively shallow. Although this piece appeared to have sufficient stock for a finish machined impeller, it was initially designated the source for high cycle fatigue test specimens. However, after vane milling this forging was redesignated for finish machining when it proved to have better cleanup at the vane inlet than the forging previously designated for finish machining.

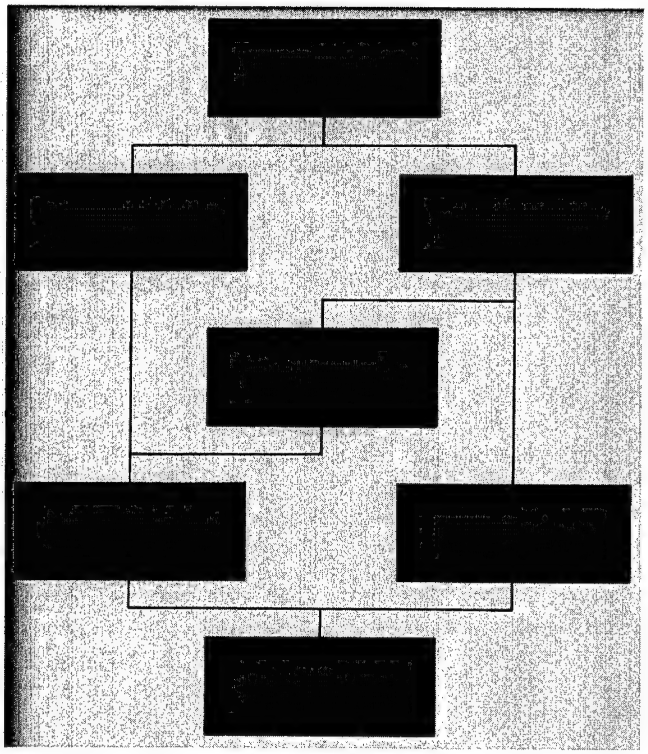


Figure 2

Forging S/N 5 shows excellent fill of the lower vane and, although there existed a lack of fill on the upper vane, it was less severe than on the other two forgings. Zyglo inspection indicated only minor surface laps.

From the above results and the billet size and weight data, it is apparent that billet configuration—specifically, the edge chamfer—was the most important factor in obtaining good fill. Forging S/N 6 had the lowest input weight and yet had the best fill.

Forging Best for Cleanup Determined

The primary purpose of the dimensional inspection was to aid in selecting the forging which would most likely clean up on machining a finished part. As formal qualification of the IITRI forging tooling was never intended to be a part of this program, only selected dimensions were inspected.

The inspection revealed an insufficient forging envelope for the vane tips at both inlet and exit. The rough machined impellers from both S/N 5 and S/N 6 verified this condition. The lack of cleanup at the inlet side of the passage fillet was not predicted during the inspection. The failure to clean up was attributed to an improper draft angle and an apparent radial variation of certain individual pocket faces from true center.

Ultrasonic Inspection Tailored to Part

The ultrasonic inspectability of any near net shaped part likely will be compromised if good material utilization is to be achieved. On the isothermally forged impeller, it was demonstrated that approximately 80 percent of the volume could be interrogated in one direction and 30 percent in two directions. This is illustrated in Figure 3 by lines superimposed on a forging cross section. Two views are illustrated so as to aid in visualizing the forging shape.

For purposes of inspecting the forged part, this degree of inspectability is believed to be acceptable for the following reasons:

- The quality of the forging billet material can be ultrasonically inspected very effectively—that is, 100 percent of its volume can be interrogated as round bar stock to at least 3/64 inch defect size.

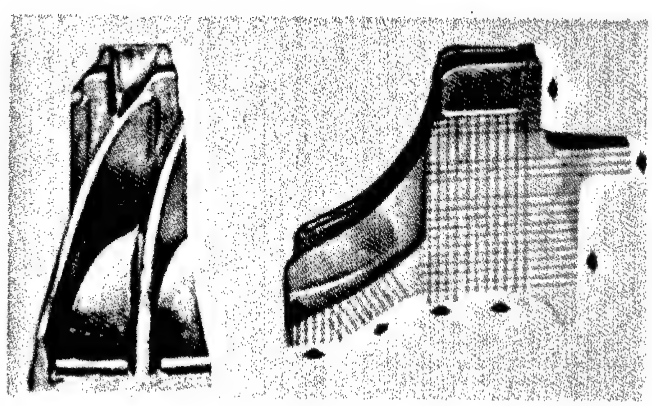


Figure 3

- Ultrasonic inspection of the part after forging serves primarily to verify that no defects were generated during the forging operation. The characteristics of the forging operation are such that only surface related defects, such as laps, will be generated by isothermal forging. Defects of this type can be determined most efficiently by Zyglo and visual inspection techniques performed before and after machining.

Further investigation will eventually be required to formulate and verify an NDE plan for a near net shaped impeller forging. Such an investigation obviously must be conducted on the configuration that ultimately is selected for production.

Metallurgical Evaluation Satisfactory

A typical macrostructure for the isothermal forging is shown in Figure 4. The longitudinal flow lines in the heavy central section are remnants of billet processing and indicate little upsetting. Flow lines show that die extremities were filled uniformly without flow laps. No evidence of segregation, inclusions, or other abnormal structure could be found.

The forging microstructure, including orientation effects (Figure 5), consists of elongated primary alpha in a transformed beta matrix and is acceptable under Avco Lycoming Specification M3403 Microstructure Acceptance Standard "c". The axis of elongated primary alpha lies predominantly along the longitudinal axis, again a billet processing remnant. Presence of primary alpha indicates that temperatures did remain below the beta transus during processing. It was observed that the volume fraction primary alpha increased at the surface to a depth of about 10 mils due to oxygen stabilization. This condition was not sufficiently severe to produce a continuous alpha case and was not considered detrimental for a part being machined all over. Results of chemical analysis showed that the weight percentages of all elements were found to fall within the ranges specified by M3403.

Mechanical Properties Adequate

Tensile tests were conducted at room temperature and 500 F (260 C). Room temperature results are marginal under M3403 specifications; however, the higher aging temperature used for the isothermal forgings could account for this effect. Elongation and reduction of area results are acceptable.

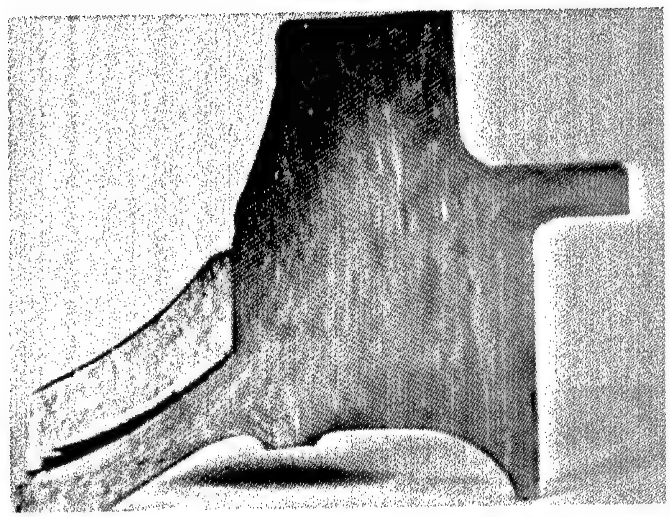


Figure 4

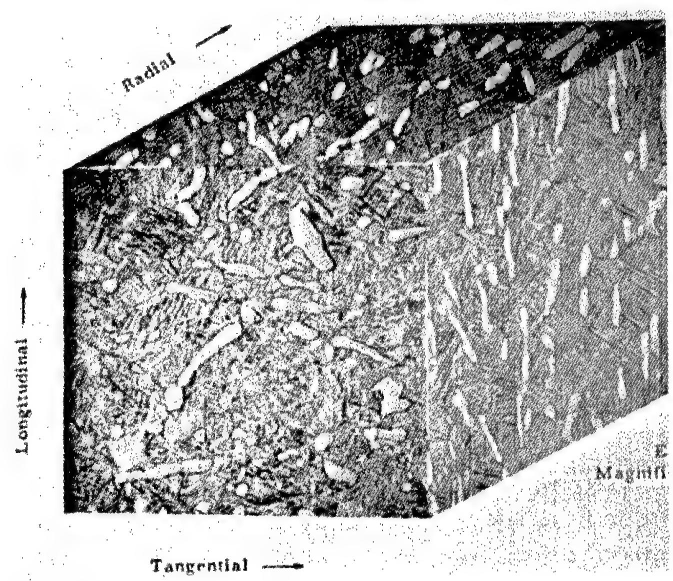


Figure 5

These tests also show marginal results with respect to design data for forgings of this cross section. One UTS value and two elongation values are low.

Notch rupture specimens were retired after sustaining a load of 185 ksi at room temperature for the required 5 hours. Subsequently, a notch tensile test was conducted.

Low cycle fatigue data were generated at 500 F (260 C) for forging S/N 10. Compared with conventionally forged Ti-6Al-4V, the isothermally forged material is equal to or slightly better than the conventional material. These results are considered to be consistent with the strength levels and general microstructure of the isothermally forged material.

When comparing the high cycle fatigue data generated at 500 F (260 C) for forging S/N 10 with conventionally forged Ti-6Al-4V, the isothermally forged material revealed a slightly lower endurance limit. However, the endurance limit of forging S/N 10 is considered to be equivalent to that of the conventionally forged material when test scatter is considered.

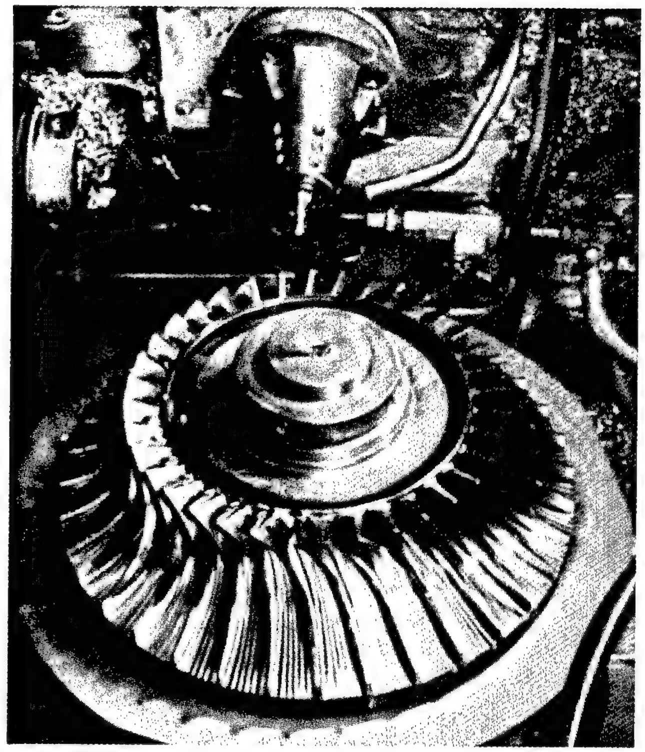


Figure 6

Current Tools Efficient But Limited

The primary purpose of machining the impellers was to determine if problems would be encountered in setting up and machining forgings with partial vane passages. Forgings S/N 5 and S/N 6 were rough machined on the bottom face and the inner bolting flange so that they could be held on the Gorton mill using existing fixturing. Because some of the normal bolting holes are used to hold the part during vane machining, one extra operation had to be added to locate and drill these holes so as to properly index the partially forged vane passages with the mill cutter.

An impeller which has just completed vane machining is shown mounted in a Gorton mill in Figure 6. Each impeller receives two complete operations in the Gorton mill, the only difference between the two being the size of the cutter. The final cut is taken with a slightly larger cutter; since the final cut is relatively light, tool side loading is reduced, deflection is low, and accuracy is high. As the Gorton mill is a mechanical cam controlled machine, the partially formed vane passages of the isothermal forging could not be utilized to effect a savings in machining time. However, no problems were experienced with intermittent machining cuts or abnormal tool wear. Solid carbide cutters are normally employed and will last typically 36 cycles before being resharpened. Cutters are purchased for finish cuts and will be resharpened once and used for roughing cuts.

The areas which failed to clean up on machining the vane passages were hand blended on impeller S/N 66 to remove a minimum of 0.010 inch (0.25 mm) and clean up any remnants of surface contamination. Following final machining, this impeller was glass bead peened per AMS 2430 to an intensity of 3-5A_2 with 400 percent coverage. The impeller was subsequently anodized and is now in engine running condition. The anodize is used as a final inspection for alpha segregation.

Material Savings vs New Tools

One of the major objectives in this program was to determine the cost reduction potential of the isothermally forged impeller. It was previously noted that isothermal forging reduced the amount of metal to be removed by nominally 50 percent, for a net savings in chips of about 13.5 lb (6.12 kg). However, while conducting the cost analysis for this part, it became apparent that component design and the production tooling concept are very influential in determining the efficiency of metal removal. These factors as well as the influence of isothermal forging on other processing costs are discussed below.

Modified Machine Tools Save, But Are Costly

The T53 impeller was originally designed so that all vane sections were radial with respect to the axis of rotation. This configuration greatly simplifies the machine tool requirement and permits the use of a cam controlled machine with only three axes. The machining concept was developed by Lycoming, and several high speed milling machines were engineered and built by Gorton. While these are only single spindle machines, it is standard practice for one operator to run an average of three machines. For the T53 impeller, the nominal cycle time is 4.8 hours, with one rough machining cycle and one finish machining cycle required per part. This has resulted in a very efficient vane machining practice; the average cost of Gorton milling of each impeller is only $130.17 (military selling price). This makes it difficult to significantly lower the cost of vane machining, even if alternative machining practices were used which would more effectively utilize the partially forged vane passages of the isothermal forging. It was previously noted that the Gorton mill—being a cam controlled machine—could not compensate for the reduced volume of metal in the vane passage by shortening the machining time.

However, in an effort to further explore the cost reduction potential of isothermal forging, a cost analysis was conducted on the use of alternate machine tooling to generate the vane passages for the T53 impeller. For this analysis, numerical controlled (NC) milling and Gorton milling with adaptive control were considered as alternates to conventional Gorton milling. The results of this analysis show that either of these alternatives can provide a significant reduction in the cost of machining, as summarized below:

	Conventional Gorton	NC	Gorton With Adapt. Control
Vane Milling Cost/Part	$130.17	$60.71	$91.10
Breakeven Point	—	7,630 Parts	5,948 Parts

From these data, it is apparent that the breakeven point is relatively high. These numbers exceed the anticipated production of 2849 units over the next eight years. This analysis confirms that for the T53 impeller the partially formed vane passages cannot be utilized cost effectively even with more advanced machining concepts. There are, however, other areas of weight reduction in the isothermal forging (approximately 6.6 lbs or 2.99 kg) that may be exploited for cost reduction purposes.

Savings on Total Cost Marginal

Almost 200 operations up to and including Gorton milling are performed on the T53 impeller. The rough machining operations are scheduled prior to heat treat to reduce the section thickness for solution treating. Since it was shown in this program that the section size of the isothermal forging was suitable for direct heat treatment, the forging can be purchased in the STA condition rather than in the mill annealed condition. This will allow the elimination of 30 operations and the rescheduling of the initial machining operations for more efficiency. Rough machining time will be reduced by a ratio that approximates the reduction of material volume. For a typical run of production parts, these cost savings per part are estimated to be as follows:

Rough Machining	$66.61
Heat Treat, Clean	4.40
Total Cost Savings	$71.01

It is obvious that this magnitude of cost reduction, which represents only about 5 percent of the total part cost, is not as substantial a number as might seem possible with a nominal 50 percent reduction in machining chips. However, it must be pointed out that for impeller designs which are more dictated by performance rather than by cost, the impact of isothermal forging on cost reduction could be much different. Machining costs escalate rapidly for high performance impellers with combinations of non-radial vane sections, a larger number of vanes, thinner vanes, or backward leaning vanes. Five-axis machine tools and lighter machining cuts to avoid tool or part deflection would be required to accommodate the more intricate vane shape. In this case, the partially formed vane passages of an isothermal forging could be more influential in reducing vane machining costs than was possible for the T53 impeller.

Forging Costs Reduced by Redesign

While the IITRI program successfully demonstrated the capability of isothermal forging, it may not be possible to determine truly representative forging costs until some reasonable production base is established. However, in an attempt to assess the impact of isothermal forging costs, the T53 impeller forging was reviewed in detail with Wyman-Gordon, Grafton, Massachusetts. Based on the results of this forging analysis and also on the above machining analysis for this part, several factors were defined.

Tooling costs will be significantly reduced in the form and detail of the vane passage can be relaxed. As discussed in the machining study, machining costs are insensitive to the volume of metal removed from the vane passage for the T53 impeller. Therefore, it would be desirable to achieve a partially formed vane passage that contributes to reducing input material costs but not to higher die costs. It was suggested by the forger that vane thickness and edge radii would have to be increased and the depth of the passage reduced to improve fill. The partially formed vane passages of the IITRI isothermal forging alone accounted for a calculated weight savings of 6.91 lb (3.13 kg). It was estimated that between one half to two thirds of this weight savings could be retained without adversely impacting tooling or production costs.

The IITRI program utilized hollow Ti-6Al-4V billet stock to produce the isothermal forgings evaluated in this program. The use of solid billet stock for future forgings is considered to be more cost effective due to higher material utilization. This will result in a solid web at the bolting flange of the finished forging, which represents about 1.5 lb (0.64 kg) of material. The hole in the hollow billet stock used in the IITRI evaluation represented approximately 15 lb (6.8 kg) of material. Hollow PM preforms have the potential to be an excellent starting material for isothermal forging; however, they have not been adequately demonstrated as yet.

Conventional forging practice requires the impeller to be heat treated only after rough machining has been accomplished. The lower mass of an isothermal forging will allow an adequate solution treatment to be obtained, as was demonstrated in this program and discussed earlier. Therefore, this allows the forging supplier to preform the heat treatment on the as forged part. Some cost savings are effected by this approach, as one annealing treatment is eliminated and qualification testing is simplified.

Cost Savings Over 8 Years Away

Based on implementing the above considerations, an engineering cost estimate was made for a slightly modified T53 isothermal forging. Using the anticipated production rates discussed previously, the per part and tooling costs are as follows:

Isothermal forging, each	$550
Tooling	$33,000

The isothermal forging cost is $61 more than current conventional forging price of $489, resulting in a net cost savings of $10.01 for each finished impeller after allowing for $71.01 cost savings due to machining, as discussed previously. When tooling costs are considered, the break-even point obviously is well in excess of the 2849 units anticipated over the next eight years.

Swelling, Loss of Elasticity Measured

Fuel Aromatics' Degradation of Rubber

PAUL E. GATZA, a Materials Research Engineer, received his B.A. in Chemistry from SUNY-Buffalo. Specializing in the technology of rubber and related nonmetallic materials, he has devoted 26 years to the development and improvement of elastomeric end items used in military equipment. Major areas of current emphasis include development of fuel tanks, drums, and hoses for the Army's Arctic Refueling System, investigation of the thermoplastic elastomers as alternate, cost effective, lighter weight materials for jacketing and insulation of electric cables, gasohol/elastomer compatibility studies, and establishment of accelerated procedures for ascertaining the hydrolytic stability of urethanes. Mr. Gatza is a member of ASTM Committee D-11 on rubber. In this capacity, he has contributed toward the evolution of specifications and standards for rubber, many of which are now recognized by both industry and the military.

PAUL TOUCHET received his B.S. in Chemical Engineering from the University of Southwestern Louisiana in 1963. He has been employed by the Material Technology Laboratory of the U.S. Army Mobility Equipment Research and Development Command at Fort Belvoir, Virginia since March 1964. In his 18 years there, he has conducted numerous research programs in the fields of elastomers, adhesives, coatings, and coated fabrics as well as serving as consultant for the development, design, manufacturing, and specifying of Army equipment utilizing elastomeric components. Mr. Touchet has been the Chief of the Rubber and Coated Fabrics Research Group at MERADCOM since May 1970.

Laboratory test fuels must be used as a standard of reference to relate their aromatic content to deterioration of rubber components exposed to them, according to findings of engineers at the U.S. Army Mobility Equipment Research and Development Command. Commercial fuels cannot be used to establish any definite relationships due to wide variations in the type and level of aromatics in these pump gasolines. The findings were the result of a MERADCOM quality assurance study performed in-house at Ft. Belvoir.

The Problem—Rubber Deterioration by Fuels

Deterioration of rubber end items such as gaskets, O-rings, hoses, and coated fabrics used in fuel handling equipment is essentially proportional to the aromatic content of the fuel to which the elastomer is periodically or continually exposed. The technology of producing gasolines and their ultimate composition is constantly changing. Ecological factors such as pollution consciousness and the uncertainties associated with immediate and future sources of supply (grade and composition of petroleum resources) have complicated further the task of keeping pace with the state of the art. Fuels having an aromatic content as high as 60% are known to be in use to satisfy certain engine performance requirements.

The evolution in recent years of three distinct classes of gasolines—leaded, low leaded, and unleaded—to satisfy tighter exhaust emission control standards has created additional confusion. Additives placed in or

NOTE: This manufacturing technology project that was conducted at Ft. Belvoir was funded by the U.S. Army Mobility Equipment R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MERADCOM Point of Contact for more information is Mr. Paul E. Gatza, (703) 664-5488.

removed from fuels to reduce emission pollution have confounded correlation of these deterioration/aromatic content relationships. Since these additives are in low concentrations, their contribution, if any, to accelerated rubber deterioration is practically impossible to discern.

Fuel resistance of elastomeric compounds generally is determined by measuring the amount of swelling and deterioration of physical properties after immersion of specimens in standard reference fuels of known aromatic content. These reference fuels are detailed in ASTM Method D-471 and Federal Test Method Standard (FTMS) 601, Method 6001. ASTM Reference Fuel A of D-471 corresponds to Medium No. 4 in Method 6001 and is composed of 100% isooctane. Reference Fuel B of D-471 consists of 70% isooctane and 30% toluene, by volume, and is equivalent to Medium No. 6 in Method 6001. D-471 also lists a Reference Fuel C which is 50/50 isooctane/toluene by volume. The nearest Method 6001 equivalent is Medium No. 5, a blend of isooctane, toluene, xylene, and benzene in a 60/20/15/5 ratio by volume. Method 6001 also references Mediums 7, 8, and 9 which consist of 100% benzene, toluene, and xylene, respectively.

Recent discoveries regarding the carcinogenic nature of benzene and subsequent OSHA directives forbidding its further use have disqualified Medium 5 of Method 6001.

The Investigation

There were five basic objectives of this program:

1. To evaluate the fuel resistance of representative elastomeric compounds exposed in commercial leaded, low leaded, and unleaded gasolines.

2. To ascertain whether relationships could be established between the severity of deterioration and the relative content of aromatic constituents or other additives in the gasolines.

3. To determine the relevance of the various aromatic components of Medium No. 5 and to determine their individual contribution to elastomer deterioration.

4. To recommend a satisfactory alternative in lieu of Medium No. 5.

5. To provide recommendations which would effect adoption of a standard series of fuels accepted by both ASTM and DOD.

The work itself was divided into two phases. The first phase encompassed determination of the extent of deterioration in physical properties of elastomeric compounds exposed to commercial fuels and gasolines of known composition. These fuels included leaded, low leaded, and unleaded types. The second phase concerned similar determinations, employing laboratory prepared test fuels, both standard and nonstandard, of varying known aromatic content.

In the first phase, 34 leaded, low leaded, and unleaded fuels were examined. They were obtained by various means—from producers, other government agencies, and laboratories—and, to maintain randomness, were purchased at service stations in the Washington, D.C. metropolitan area. Additionally, Reference Fuels B and C of ASTM D-471 and Medium No. 5 of FTMS, Method 6001, were included as typical currently used reference standards.

Gas chromatography and other laboratory analytical procedures were employed to obtain a breakdown of each fuel in terms of aromatic concentration—by type or chain structure—and tetrethyl/tetramethyl lead content. A good representative range of aromatic content was obtained—from a low 8.1% to a relatively high concentration of 62.9%.

Seven elastomeric compounds representative of those used in applications requiring fuel resistance were selected, mixed, and vulcanized as 6 by 6 inch test sheets having a thickness of about 0.080 inch. Elastomer types included neoprene; high, medium, and low nitriles (NBR); nitriles/PVC; epichlorohydrins (ECO); and polysulfides.

Fuel resistant elastomers also play a significant role in military applications as coated fabrics in fuel handling equipment and related end items. Therefore, two fabric coating materials, a polyether urethane and a polyester urethane, were also included in this study. These materials, whose formulations are proprietary, were supplied in large cured sheets by Uniroyal, Inc. the manufacturer.

In the second phase, formulations and sample preparation were the same as in Phase I, except for the exclusion of two compounds—the medium nitrile and the polysulfide. Sufficient materials were prepared initially in the laboratory or were obtained from Uniroyal, Inc. to conduct all tests under both phases. Fuels used in Phase II were the standard ASTM D-471 or FTMS 601, Method 6001 reference fuels or variations thereof. The variations were selected to ascertain more precisely the relationships between toluene, xylene, and benzene as are encountered in fuels such as Medium No. 5. Additional data obtained

could then be subjected to analysis by computerized reduction techniques.

Initial physical properties—tensile strength, elongation, 200% modulus, and Shore A hardness—were determined according to procedures detailed in ASTM D-412 and ASTM D-2240. Volume swell after 4 and 7 day room temperature immersion for Phase I and Phase II tests, respectively, was determined according to Method 6211 of FTMS 601. Retention of tensile strength and elongation after immersion was ascertained according to FTMS 601, Method 6111, with values obtained based on the swollen cross sectional area per paragraph 4.8.1 of Method 6111. The diffusion rate tests (Phase I only) were performed in accordance with the provisions of MIL-T-52573, paragraph 4.6.2.2, typically used to evaluate coated fabric materials for fuel tanks. Test procedures followed were similar for both phases of the program. However, all fuel immersion tests were not conducted in either phase. Data obtained were deemed sufficient to substantiate conclusions and recommendations.

Phase I Findings—No Surprises

The data for total aromatic content of the 34 different fuels examined during Phase I underscore the wide variation in composition and ultimate deleterious effects on elastomeric compounds observed in this investigation. When categorized according to lead content, the unleaded and low leaded fuels display the widest range—24.4% to 56.6% and 8.1% to 62.9%, respectively. The leaded fuels occupy a narrower mid-range area—26.7% to 38.6% aromatic content. As aromatic content decreases, a proportionately greater amount of these components are classified under C-9 and C-10 groupings, the exact structure of which is indeterminate.

The data were organized as input to in-house computerized regression analysis software routines. It was hoped that this analysis would uncover certain patterns or relationships linking a particular aromatic constituent with the severity of deterioration observed for one, several, or all elastomers. No satisfactory correlation could be established. More sophisticated techniques involving stepwise linear regression then were applied. Here again, results were inconclusive. Aromatic groups (variables) removed early from the stepwise analysis of one rubber were retained until the end for another rubber. Also, in most cases, regression was complete after few passes.

Data for those rubber/fuel exposures which were employed throughout the Phase I study were plotted as bar graphs for each of the nine rubbers. Percent tensile retention and volume swell for these unleaded, low leaded leaded (where included), and test fuel/rubber combinations for the high nitrile NBR rubber are shown in Figure 1. While no distinct pattern applicable to all rubber/fuel combinations is discernible, certain generalizations can be made. Unleaded fuels tend to produce greater tensile strength loss and higher volume swell than low leaded or leaded fuels. In some cases (all NBR's, neoprene, and the two urethanes), tensile loss is somewhat greater than that observed for the three test fuels, which also contained no lead. In the four situations where low leaded and fully leaded fuels can be compared, results are mixed, with the presence of additional lead having no correspondingly greater adverse effect on tensile retention or volume swell.

Four of the five unleaded fuels, only one of the low leaded fuels, and none of the leaded fuels compared contained an aromatic content of over 40%. When this factor is considered in evaluating the data or in considering the whole spectrum of rubber/fuel combinations studied, the results fall in line with what one could predict. Higher aromatic content results in more severe swelling and deterioration, regardless of the presence or absence of lead. Likewise, the test fuels currently used remain fairly reliable indicators of performance. However, it becomes obvious that test fuels having 40%, 50%, or, perhaps, even 60% aromatic content must now be used to ensure adequate evaluation of elastomer performance. Finally, among the representative elastomer types evaluated, ECO, polysulfide, high NBR, and the ester polyurethane are preferable choices if other requirements do not preclude their use.

Diffusion of the fuels through circular specimens of the nine rubbers generally follows the same pattern as the other properties evaluated. Higher aromatic content fuels escape through the rubber at a faster rate than those of low aromatic content. The low rate of fuel escape shown by the ester urethane is one significant reason why this material is now being used in fabrication of coated fabric fuel handling equipment in preference to the previously favored but more porous low and medium NBR's and neoprene.

Phase II—How Good Are The Tests?

Previous studies of the performance characteristics of fuel resistant rubbers have shown that swelling and loss of tensile strength and elongation stabilize after 48 to 96 hours' exposure. Prolonged exposure beyond 96 hours may produce further changes, but they are of little

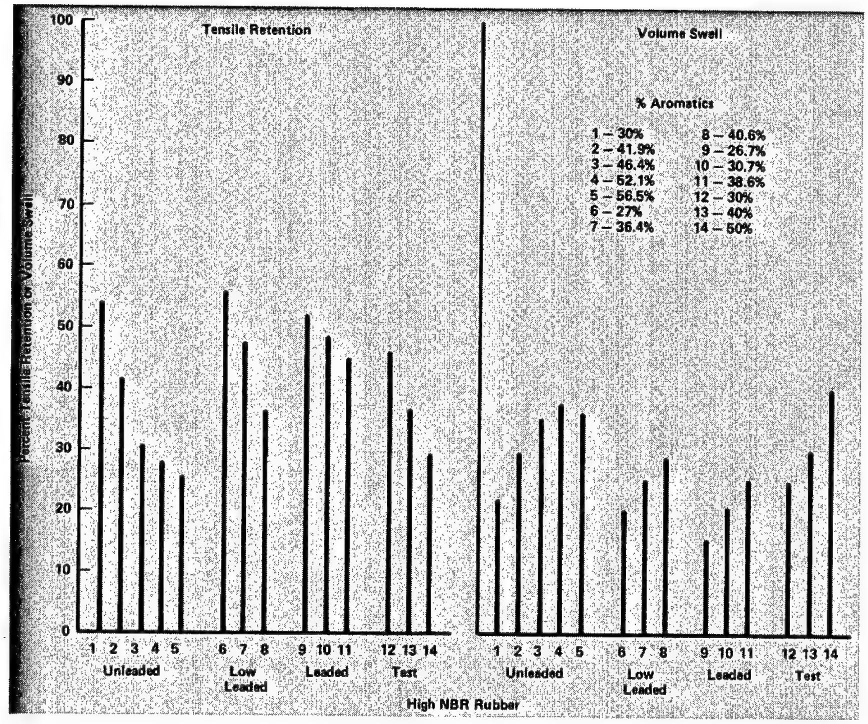


Figure 1

significance. Seven days' exposure time was employed in Phase II tests to ensure that all test fuel/rubber combinations had stabilized, particularly those having 60% and 70% aromatic content - levels not generally employed previously.

Elongation retention data are a bit erratic, and some anomalies are usually evident. However, tensile retention data and, particularly, the volume swell data as presented in Figures 2 and 3 clearly show that there is no leveling off or plateau effect. Degradation of strength and swelling continues at a rate proportionate to the total aromatic content of the test fuel. At the 60% aromatic content level (observed in some of the Phase I commercial fuels) volume swell of neoprene and low NBR, two of the most commonly used elastomer types, exceeds 100% and less than 20% of the original tensile strength is retained. Superiority of the polyester urethane is apparent and is further evidenced by the fact that even at the 100% aromatic level, the swell of this rubber is less than 60%.

How well do these test fuels reflect performance characteristics elastomeric compounds exposed directly in commercial fuels? This was examined by extracting data from the Phase I work which could be compared with results from Phase II. Data for the low and high NBR's and the two urethane rubbers exposed in unleaded fuels of 30% and 50.8% aromatic content and low leaded fuels of 40.6% and 62.9% aromatic content were compared. Correlation of test and commercial fuel data is generally good, the only significant exception being the lower volume swell of the polyester urethane in the commercial fuels. This comparison again demonstrates that the presence or absence of lead in a commercial fuel to which an elastomeric compound is exposed is not as important as the selection of test media having comparable or slightly higher aromatic content.

The issuance of directives forbidding the use of benzene in test fuels prompted further work to ascertain whether this carcinogen could be eliminated from Medium No. 5 of FTMS 601, Method 6001 and replaced with toluene or xylene. Volume swell testing was conducted, therefore, on six laboratory prepared test fuels having the following composition:

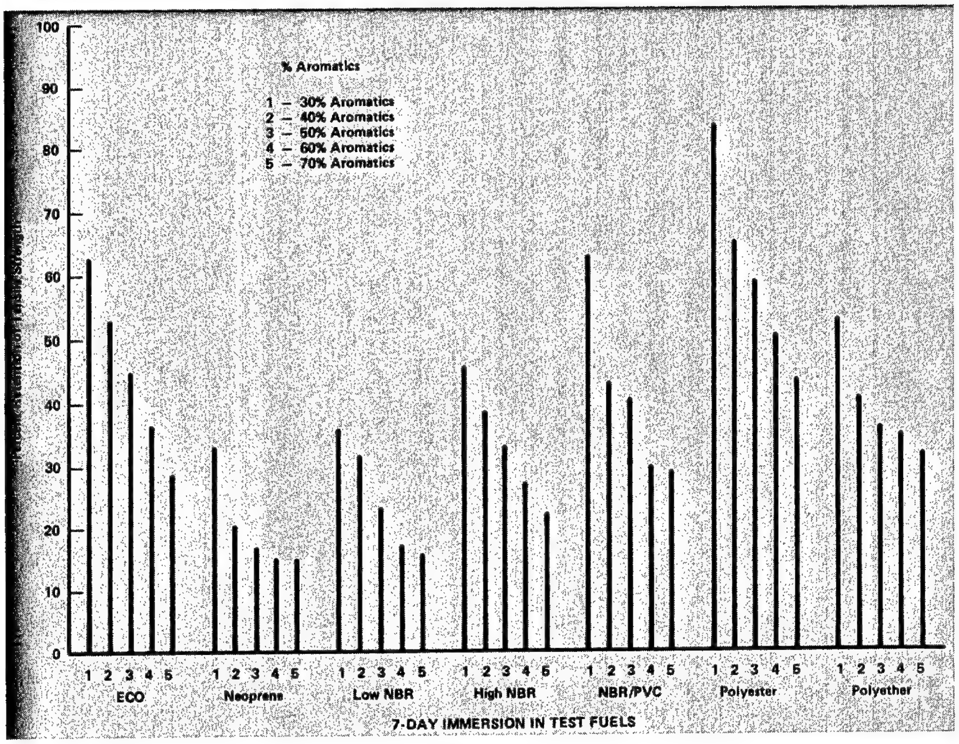


Figure 2

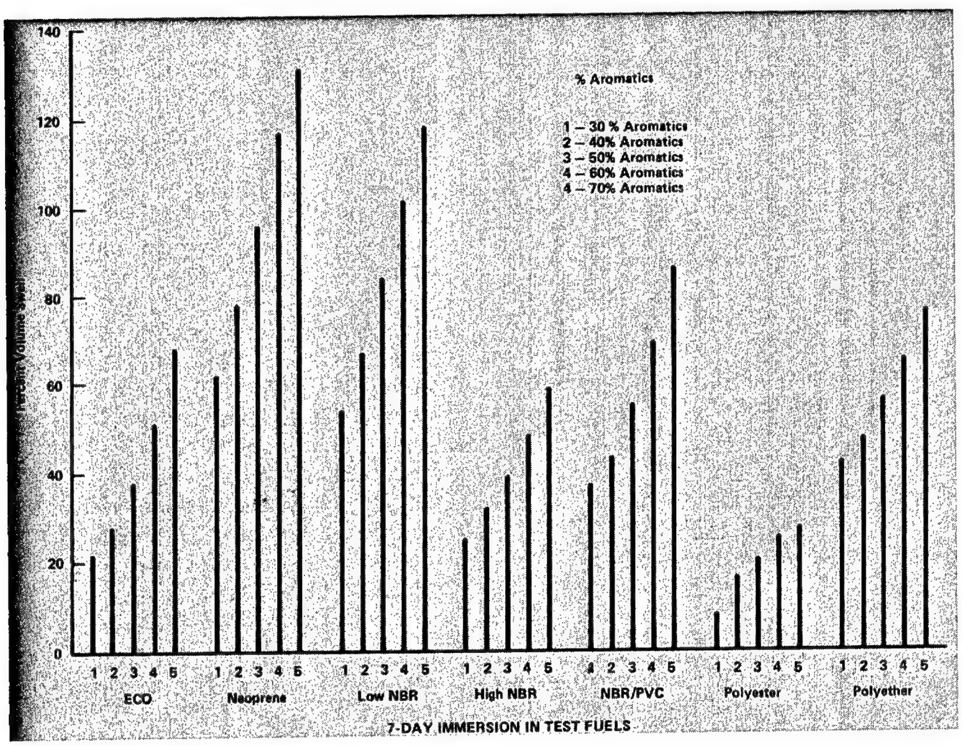


Figure 3

Isooctane (%)	Toluene (%)	Xylene (%)	Benzene (%)
60	40	0	0
60	25	15	0
60	20	15	5
60	15	20	5
60	20	5	15
60	5	15	20

Volume swell results for each of the seven Phase II rubbers exposed in the above test fuels showed that there was no significant increase or decrease in volume swell attributable to variation in benzene content. Any swell variance of less than 5% such as occurred here is easily within the span of allowable experimental error. These data also indicate that the necessity for inclusion of xylene in Medium No. 5 is questionable. A reference fuel consisting of 60% isooctane and 40% toluene would be adequate as a replacement for Medium No. 5 and as an additional 40% aromatic reference fuel in ASTM D-471.

Data generated in the above benzene study and other Phase II work provided sufficient information to attempt prediction of the volume swell of randomly selected test fuels wherein the isooctane content was varied between 30% and 70% and the toluene, xylene, and benzene, between 0% and 50%. The composition of the constitutents of the tested fuels, expressed as a percentage of the total volume, together with observed volume swells for the seven Phase II rubbers formed a matrix of data input to a computer program for simplified regression analysis written in Basic language. Regression coefficients obtained then were used to calculate the predicted volume swell for untested rubber/fuel combinations. To spot check for accuracy, volume swells for nine selected untested rubber/fuel combinations then were determined.

Agreement between actual and predicted volume swell in the nine cases where the comparison was made was excellent. More important, however, is the fact that closer examination of the predicted volume swell data lends further support to the rationale for selecting a 60/40 isooctane/toluene mixture as a replacement for Medium No. 5. In all Phase I work, the benzene content of the commercial fuels never exceeded the 5% level of Medium No. 5. When the 40% aromatic content consisted entirely of benzene, in three cases (ECO, neoprene, and low NBR) the predicted volume swell exceeded that of the test fuel containing 40% toluene. However, when the test fuel contained only 40% xylene, the predicted volume swell for ECO, low NBR, and the NBR/PVC rubbers was significantly lower, and in none of the other cases did it exceed that of the 40% toluene test fuel by more than 4%. Finally, even when the prediction matrix was extended to include combinations of 60% aromatic content, volume swell values were predominantly within the range of the ±5% allowable for experimental error.

What Does This All Mean?

In addition to the conclusion found at the beginning of this article, several other relevant facts came to light:

- The presence, absence, or concentration of lead in commercial fuels cannot be correlated with relative degradative effects on elastomeric compounds.
- Unleaded fuels by virtue of their generally higher aromatic content are somewhat more deleterious to rubber compounds, but anomalies, presumably related to the presence of other additives, may occur when comparisons are made with low leaded or leaded fuels.
- Changes in physical properties of elastomeric compounds exposed in laboratory test fuels of increasing aromatic content (30-70%) occur at a rate proportionate to the aromatic content. No leveling off or plateau effect is discernible.
- The benzene content of commercial fuels is less than 5%, a level low enough to justify elimination from laboratory test fuels in compliance with OSHA directives.
- Substitution of additional toluene for both xylene and benzene in Medium No. 5 of FTMS 601, Method 6001 will have no adverse effect on the reliability of estimating the deleterious effects of fuels on elastomeric compounds.
- A new reference fuel consisting of a 60/40 ratio of isooctane and toluene by volume should be included in both ASTM-D471 and FTMS 601, Method 6001 to fill the need for a 40% aromatic test medium.

ASTM has taken appropriate action, The recommended 60/40 isooctane/toluene test fuel was approved by the cognizant D-11 Committee and now appears in ASTM D-471 as Reference Fuel D.

Fired At Angles From Moving Sites

Projectiles Targeted Acoustically

DONALD E. FRERICKS is a project engineer with the U.S. Army Armament Research and Development Command at Rock Island Arsenal, Illinois. There he is responsible for weapon test programs and unique/advanced simulation technology and equipment design. Before joining ARRADCOM in 1978, he performed similar projects for the Rodman Laboratory at RIA for nine years. He eariler spent three years with the Bendix Corp. working on fluidic research and cryogenic valve design for the space program after spending four years with NASA's Goddard Space Flight Center in preflight test and checkout of scientific satellites. Mr. Frericks received his M.S. in Engineering from Catholic University in 1966 after taking his B.S. in Mechanical Engineering at Iowa State University in 1960.

Sample firing of freshly produced rounds will not hold up accelerated production of U.S. Army ammunition following the development of an automated electronic target scoring system for small caliber weapons. This new system, which resulted from a U.S. Army Armament Research & Development Command project, uses acoustics to detect and target score supersonic projectiles. Annual cost savings of $15,000 will be experienced using present capability, with savings growing to $35,000 when the full capability of the targeting system is realized. Test firing of 20 mm and 30 mm rounds will be practical at that time.

A unique feature of the technique is that the axis of fire does not have to be perpendicular to the plane of the target area. A dual rod concept using acoustic sensors was developed to alleviate this design problem. This unit allows accurate target scoring of projectiles fired from a test platform that may be moving in combined yaw-pitch motion. Another new feature is the 250% increase in length of burst, which enables burst statistics to be achieved from a larger sample.

The objective of the ARRADCOM project was to select, purchase, install, and check out an electronic target scoring device using already developed scientific principles and commercial equipment without drastically modifying procedures.

Earlier Efforts Impractical

The traditional method of manually measuring target positions of projectiles has become too time consuming and costly. Recently, some semiautomated techniques using galvanometer slide wire devices have been introduced to accelerate the measuring process. Fully automated scoring devices using acoustic sensors as targeting aids have been developed for use with small caliber projectiles fired in relatively long (100 meter plus) indoor ballistic ranges. When acoustic sensors are used in small indoor ranges, echoing occurs causing false triggering. Currently, there is only one commercial system capable of fulfilling the military's needs for targeting systems; but since the sensors used with that system are a proprietary item of the company, the system is not available.

In a prior effort, an automatic targeting system was developed and a prototype built using light sensing diodes to track the projectile path. However, this idea was abandoned because the system could not be adapted practically for large area scoring.

NOTE: This manufacturing technology project that was conducted by The Ware Simulation Section at Rock Island Arsenal was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact is Donald E. Frericks (309) 794-6868.

Shockwaves Measured

The scoring device that was selected and installed was an Accubar Model ATS-16D using the underlying physics principle of acoustic shock wave propagation. This principle has been used for several years in determining the x-y coordinates of supersonic projectile impact points. In addition, work was performed to develop an algorithm for measuring impact points and computing velocity of the projectile. The automatic target scoring device can be adapted to a PDP-8E Minicomputer and M1709 Interface.

A ballistic projectile exceeding the speed of sound creates a shockwave perpendicular to the shock front. The high energy, fast moving shockwave appears as a cone expanding at the speed of sound (Figure 1) which can be detected easily by ceramic piezoelectric transducers. These are located on the ends of aluminum sensor rods which are mounted at the edges of the scoring plane. The transducers detect the shockwave that has been induced into the metal rods. The relationship of shockwave to transducer rods is shown in Figure 2. The expanding shockwave strikes the rod sensors at tangent points, generating secondary shockwaves within each rod. These secondary waves move in opposite directions at the speed of sound in metal (about 15 times faster than in air) and excite the transducers at the rod ends. Each of the rods and its associated transducers and circuitry acts independently of the other to provide one axis of the readout.

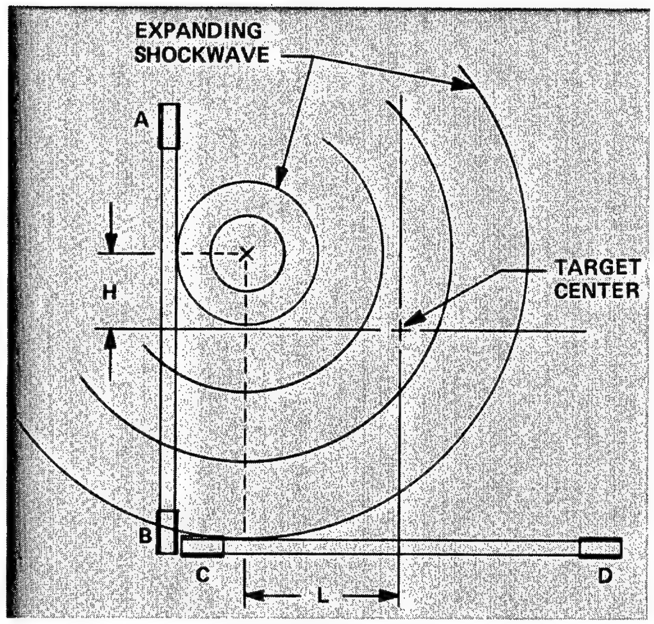


Figure 1

Up to 6000 Shots/Minute

In the example shown in Figure 2, the round passed through the target plane high and to the left of center. The point of tangency on the y-axis results in the secondary shockwave reaching the top transducer first; this action starts an electronic clock circuit, and when the secondary wave in that rod reaches the bottom transducer, the clock circuit is shut off. Appropriate circuitry allows a readout or display of the accurate location of the initial point of tangency.

The final display of the hit or miss location can be in a form that is amenable to the system requirements. It can be a digital lamp display, paper printout, cathode ray tube

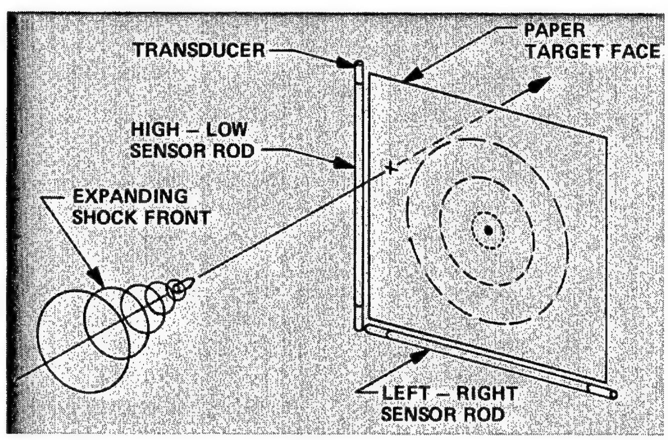


Figure 2

display, or cards punched for computer analysis. An important feature is the rapid reset time and, therefore, the rapid scoring. By the use of a 1.2 m square target, as an example, the acoustic disturbance from the shockwave will pass the rods within 5 to 15 milliseconds apart and results in the scoring of approximately 4000 to 6000 shots per minute.

When the shockwave reaches the x-rod, these actions are duplicated in the x-axis. The resulting x-y coordinates can locate the point where the round passed through the scoring plane to within 0.25 cm.

System Unaffected By Temperature

The relative measurement that is occurring in the rod sensors makes this target scoring system unique. The intensity and rise time of the ballistic shockwave are unimportant and have no effect on accuracy. The total length of the rods and any changes in the rod lengths because of temperature do not affect accuracy.

This system has been designed and developed for use in firing tests wherein the flight path of the projectile isn't required to be perpendicular to the target plane. To accomplish this, the system features a unique coplanar arrangement of rods; two are mounted vertically and two horizontally with a sensor attached to the edges, allowing the scoring points in each axis to be triangulated to the actual impact point on the target. The sensor rods, when mounted as previously mentioned, detect the ballistic shock wave, which causes an electrical pulse to be generated by piezoelectric transducers located at the rod ends. These pulses are processed within the system (Figure 3), then the relative position of the projectile is automatically computed.

Computer Link Expands Data

When fully utilized, the system will be extremely efficient, accurate, versatile, and capable of scoring small

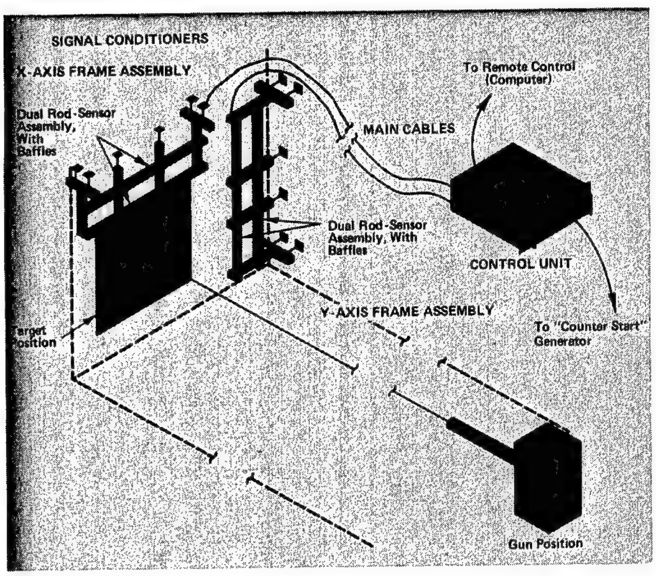


Figure 3

caliber targets automatically with minimal range treatment. Also, when coupled with a computer, the system can produce additional statistical parameters other than impact points (e.g., extreme horizontal/vertical points, extreme spread, and various standard deviations, etc.). However, burst firing of 20 mm and 30 mm rounds cannot be done without treating walls and floors with a material that will absorb and/or break up the reflected shock waves.

The system also provides a firing interrupt signal and shuts off weapon firing as impact points approach the outer edges of the target area; this feature enhances the capability of the six degree of freedom simulator located at the Ware Simulation Center.

An additional benefit is that the maximum burst length using color coded ammunition and paper targets is increased 250%—from 20 rounds to 50 rounds.

Polyimide MLBs Immune

Preventing Plated Through Hole Cracking

LLOYD WOODHAM is Project Manager in Computer Aided Design and Computer Aided Manufacturing, System Engineering Directorate of the Army Missile Laboratory, U.S. Army Missile Command. He came to Redstone Arsenal in 1958, starting in the U.S. Army Missile Electronics Laboratory after graduating from Smith—Hughes, Atlanta, Georgia, in Electronics Technology. Among his first assignments was technical support in the assembly of the Army's Redstone tracking station, which was used to determine Sputnik's orbit and to track a number of later Satellites. He later transferred to the Advanced Sensors Directorate and became a Group Leader. He established and managed the first printed wiring board manufacturing facility at Redstone, which grew into the System Engineering Directorate's existing facility. He started work in the Manufacturing Technology Division in 1977.

Cracking of the copper plating in the plated through hole (PTH) is a common failure mode and often considered the most important problem affecting production yields of high reliability multilayer boards (MLBs). Fabricators of MLBs long have been concerned with this recurring problem, which is observed on cross sections of test coupons after the thermal stress test specified in the MIL-specs (solder float at 550 F for 10 seconds). In addition, there always exists the possibility of cracked PTHs in other MLBs in which the coupons were found to be crack free since there is still not data available correlating the coupon to the actual MLB.

This program was initiated by MICOM to determine methods of eliminating the cracking of PTHs by establishing an optimum copper plating bath with the necessary controls to produce crackfree copper deposits, and by identifying MLB laminate materials with low z-axis expansion and high glass transition temperature (Tg) values. The work was performed by Hughes-Fullerton.

PROGRAM SUMMARY

Phase I of the program was dedicated to evaluating copper plating baths available in the PWB industry. The baths were evaluated by plating copper foil daily from each of the candidate baths for 20 days and measuring elongation, tensile strength, and hardness. Based on this data, two baths were chosen for the production simulation tests.

In Phase II, MLB laminate materials were tested for Tg and z-axis expansion and subsequently used to fabricate MLBs for use in Phase III.

In Phase III, several procedures were established for controlling the copper baths within optimum operating limits. MLBs were fabricated using epoxy-glass, polyimide-glass, and Cor-Lam®. These MLBs were drilled and plated in each of the candidate plating baths in a production mode. Eighteen MLBs (six of each material type) per bath were plated daily for 10 to 12 weeks. The MLBs then were subjected to thermal stress tests, microsectioned, and examined for cracks. The results were analyzed to determine the best combination of laminate material and copper plating bath for use in the production of high reliability MLBs. Also, a handbook was prepared documenting the processes and controls necessary to produce the optimum MLBs. Table 1 outlines the program.

NOTE: This manufacturing technology project that was conducted by Hughes-Fullerton was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorage for Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Lloyd Woodham (205) 876-5742.

Phase I — Evaluation of Copper Plating Baths • Develop background information • Evaluate copper plating baths • Choose best baths for production simulation task
Phase II — Evaluation of MLB Laminate Materials • Conduct industry survey • Fabricate test MLBs using epoxy-glass, polyimide-glass and Cor-Lam® • Test MLBs for Tg and Z-axis expansion
Phase III — Production Simulation • Establish controls for copper baths in production mode • Fabricate production quantity of MLBs Epoxy-glass Polyimide-glass Cor-Lam® • Plate MLBs in copper baths Acid Pyro 36 MLBs/day for 10-12 weeks • Subject MLBs to thermal stress test Solder float at 550 F for 10 seconds • Microsection and examine for cracks • Correlate data and analyze results

Table 1

Copper Plating Baths Examined

To select candidates for evaluation, an investigation was conducted of existing technology pertaining to the problem of PTH cracking. This included a literature search and industry survey for existing technology and an analysis of existing data from past Hughes experience. This was done to ensure the incorporation of all available information in the selection processes.

The candidate copper plating baths were chosen after close examination of physical and chemical characteristics of ten possible plating systems (see Tables 2 and 3). The chemical characteristics of each of the plating baths were compared for stability and ease of operation. Parameters including temperature, agitation, component concentrations, bath additive concentration, and current density were evaluated. Copper deposits of 2.5 to 3.0 mil thicknesses obtained from each of the plating systems were tested for ultimate tensile strength, elongation, and hardness.

Bath Name (Vendor)	Copper (g/l)	H_2SO_4 (g/l)	Cl (ppm)	HBF_4	Additive
CUBATH® M (Sel-Rex)	17	173	50		(1)
Copper Gleam® PCM (Lea Ronal)	19	188	75		(2)
Copper-Lume™ PC (M&T Chemicals, Inc.)	19	188	50		(3)
Enplate® HT (Enthone, Inc.)	23	225	60		(4)
CU-TRONIX® (Harshaw Chemical Co.)	28	210	25		(5)
Acid-Copper, Nonadditive (None)	19	188	50		
Copper Fluoborate (None)	16			220	

(1) MHY, 20 ml/gal; Maintenance, 0.3 ml/Amp-hr
(2) PCM, 0.5%, Maintenance, 0.5 ml/Amp-hr
(3) PTH, 0.6%, Maintenance, 0.5 ml/Amp-hr
(4) HT1, 5 ml/l; HT2, 1 ml/l; HT3, 0.02 ml/l
(5) CXA, 2%; CXB, 1.5%; NPA, as Required

Table 2

Bake Improves Ductility

It was demonstrated that a postplating bake of 300 F for two hours significantly improves the ductility of electrodeposited copper. This was especially true for deposits from baths with organic additives—except for the Harshaw deposit, which has an initially high value. In addition, pulse plating and periodic reverse rectification cycles did not improve (over standard DC rectification) the physical properties of the deposited copper.

Based on the results of this bath screening task, the Sel-Rex sulfate bath was selected as one of the candidate baths for use in Phase III, and a 300 gallon bath was installed for production use for PWBs and MLBs. The M&T pyrophosphate with organic additive was also chosen because approximately one half of the industry producing high reliability MLBs presently uses this bath, and the ductility of the copper in the "after back" condition (16 percent) was sufficiently high. In addition, pyrophosphate baths have been used at Hughes-Fullerton for many years in production, and a large pool of information was available relative to controlling this bath in a production environment. The results shown in Tables 4 and 5 represent the average of sixty tests for each bath evaluated.

Bath Name (Vendor)	Copper (g/l)	Pyro-phosphate (g/l)	NH_3 (g/l)	pH	Free CN (g/l)	NaOH (g/l)	Rochelle Salts (g/l)	Temper-ature (°F)	Addi-tive
Unichrome™ (M&T Chemicals, Inc.)	23	180	3	8.3				120	(1)
Unichrome™ (M&T Chemicals, Inc.) Nonadditive	23	180	3	8.3				120	—
Copper Cyanide (None)	15				12	30	60	130	
(1) PY61H, 4ml/gal, Maintenance, 125 ml 1000 Amp-hr									

Table 3

Physical Properties \ Baths		Pyro W/O PY61H		Pyro W/PY61H	Cyanide	Fluoboric W/Additive
		DC	Pulse	DC	Pulse	DC
Percent Elongation	As Plated	8.7	1.6	3.4	2.3	4.9
	After Bake	10.5	4.5	15.0	2.5	8.8
Ultimate Tensile Strength ($X10^3$ psi)	As Plated	65.2	68.0	93.2	27.4	38.0
	After Bake	55.0	40.0	34.2	25.2	24.7
Knoop Hardness	After Bake	130	108	120	106	101

Table 4

Laminates Tested

A review of the literature and a survey of laminate vendors produced three laminate materials for evaluation: epoxy-glass, polyimide-glass, and an epoxy-polyimide-glass laminate called Cor-Lam®

Test MLBs were laminated using the time, temperature, and pressures recommended by the laminate vendors. Samples of the MLBs then were submitted for measurement of z-axis expansion using a thermal mechanical analyzer. Tg data was obtained using a differential scanning calorimeter.

Physical Properties \ Baths		Sel-Rex		Lea Ronal		M&T		Enthone		Harshaw		Copper Sulfate W/O Addition	
		DC	Pulse	DC	Pulse	DC	Pulse	DC	Pulse	DC	Pulse	DC	Pulse
Percent Elongation	As Plated	8.2	5.2	8.1	4.8	9.4	5.8	9.7	4.5	14.0	13.3	7.3	6.1
	After Bake	19.6	12.8	12.5	9.3	16.5	12.1	13.0	8.1	15.0	13.7	12.0	6.5
Ultimate Tensile Strength ($X10^3$ psi)	As Plated	76.0	82.0	72.4	70.0	71.0	60.1	52.2	70.9	44.0	40.6	28.0	30.0
	After Bake	41.3	38.0	38.0	37.4	40.0	40.2	39.0	39.2	41.2	37.2	30.1	26.7
Knoop Hardness	After Bake	105	103	112	108	111	105	105	103	114	106	115	125

Table 5

Similarly, Tg and z-axis data were obtained from samples of C-stage and mass laminated MLBs of epoxy, polyimide, and Cor-Lam material. The Tg of epoxy-glass ranged from 118 to 125 C, whereas the Tg of polyimide ranged from 240 to 287 C. The Tg of Cor-Lam was somewhat higher than epoxy at 154 to 158 C, but significantly lower than polyimide glass.

Thermal Stress Test Conclusive

The comparative results of the z-axis expansion measurements for each of the three laminates is graphically shown in Figure 1. Here, one can see the tremendous difference between the z-axis expansion of epoxy-glass and polyimide-glass at the solder float temperature of 550 F (288 C). Based on this data, it is very apparent that polyimide-glass is better suited to withstand the effects of the thermal stress and temperature cycling tests specified in the MIL-specs. A comparison of the expansion of an 0.060 inch thick MLB from room temperature to 550 F is shown below.

- Epoxy-glass ~ 3 mils
- Cor-Lam ~ 2.5 mils
- Polyimide-glass ~ 0.9 mil

It is also very apparent from the above figures that the copper plating in epoxy-glass boards has to stretch significantly more than the copper in polyimide-glass MLBs. The Cor-Lam material, a product of DuPont, was on the market for approximately a year but has been discontinued.

Plasma Cleaning Effective

Processes for cleaning, sensitizing, and plating of the drilled holes were also evaluated in this task. Plasma cleaning of the drilled holes prior to the sensitizing and electroless copper process resulted in a viable process for all three types of laminate materials. The MLBs were placed in a plasma chamber and the holes were desmeared and slightly etched using a gas mixture of freon and oxygen. The plasma cycle was followed by an immersion of the boards in a solution of hydrochloric acid and ammonium bifluoride to prepare the exposed glass fibers for the subsequent standard electroless and electrolytic plating processes.

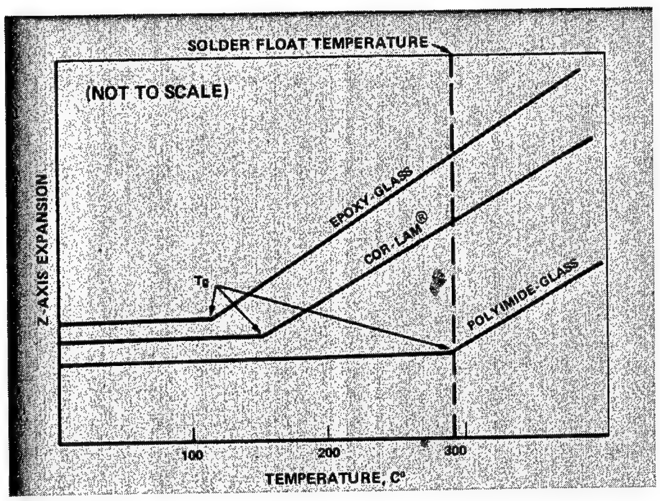


Figure 1

Parameters Optimized

Tests were made on the production plating solutions to optimize the bath parameters. The concentrations of the various components of the candidate baths were investigated to determine the effect of each on the throwing power and deposit quality. This was accomplished by conducting Haring cell tests on baths in which the concentration of the copper was 50 percent and 150 percent of the vendor's recommended values. Similar tests were conducted on the baths in which the other constituents were varied in a similar manner. The results verified that the optimum chemical makeup for each of the baths was that specified by the vendor; therefore, no changes were required in the operating limits of these baths.

Production quantities of MLBs were fabricated using epoxy-glass, polyimide-glass, and Cor-Lam® laminate material. Epoxy and polyimide boards were produced using the mass lamination technique, while the Cor-Lam boards and additional epoxy and polyimide boards were laminated in the one-up configuration. The amount of cure or polymerization was determined by performing glass transition (Tg) tests. Data obtained from these tests was used to establish Tg limits for each of the laminate materials.

Production Simulated

The MLBs were drilled and plated in each of the production plating baths on a daily basis for a period of 12 weeks. Six MLBs of each laminate material type were

plated daily in the Sel-Rex acid sulfate bath and a similar number in the M&T pyrophosphate bath for a total of 36 boards a day. To ensure good integrity of the plated copper, the pyro production baths were qualified on a daily basis prior to plating of production boards. This procedure has been used at Hughes for years with good results. The qualification test consisted of plating test boards in each of the baths, subjecting them to the solder float test, and examining the microsections of the PTHs for evidence of cracks. When test boards exhibited cracks, the corresponding bath would be suspended and corrective action would be taken to put the bath into acceptable plating condition.

This qualification task was not performed in the beginning on the acid-copper bath and is therefore referred to as the nonqualified bath. Since a great number of PTH failures were being obtained in this bath, it was replaced with a new acid bath and referred to as Acid Bath Number 2. A qualification procedure similar to the one used for the pyrophosphate bath was immediately instituted for Bath Number 2, and an additional twelve weeks of plating data was obtained for this evaluation.

Once the boards had been plated and baked at 300 F for 2 hours, test coupons were removed from the MLBs and submitted for testing.

Molten Solder Test Important

Each MLB had a test coupon removed and tested per the thermal stress requirement of MIL-P-55110C. The coupons were routed from the test boards rather than punched to minimize possible coupon damage.

The thermal stress outlined in MIL-P-55110C was designed to simulate the effect of the circuit board passing over a molten solder wave. Thus, testing to this specification ensures the MLB's capacity to be production soldered without failures occurring.

The thermal stress tests were performed in the following manner:

1. The specimens were conditioned at 250 F to 300 F for a minimum period of two hours to remove any residual moisture.

2. The specimens were placed on a ceramic plate in a desiccator and allowed to cool to room temperature.

3. The specimens were then fluxed (type RMA of MIL-F-14256) and floated for a period of 10 seconds in a solder bath of $63(\pm 5)\%$ tin maintained at $550(\pm 10)$ F. The solder temperature was measured with the thermocouple probe no deeper than one inch from the surface of the molten solder.

4. After the solder float, the specimens were removed from the solder bath and placed on an insulator to cool to room temperature.

Polyimide PTHs Excellent

The PTH examinations were accomplished as follows. The test specimens were mounted so that the plane of the cross section was perpendicular to the plane of the deposit to be measured. The specimens were molded in a thermosetting plastic conventionally used in metallography and polished with a suitable medium having a particle size of not more than 0.3 micron. Polished sections were always etched so that any trace of soft metal smeared over the harder metal during previous operations was removed. This also provided contrast between the various layers of plated metal. The visual examination for cracked copper in the prepared microsections was carried out at a magnification of 200X as specified in MIL-P-55110C subparagraph 4.8.1.

The results of this task have been tabulated and are shown in Table 6. The test results indicated that polyimide-glass as a substrate produced MLBs immune to PTH copper cracking under all test conditions.

No evidence of cracked PTHs in polyimide-glass MLBs was observed in 4824 holes examined in 26 weeks of production. This included more than 11 weeks of simulated production plating in the nonqualified acid-copper bath. A low incidence of cracked PTHs was

Board Material / Bath Type	Epoxy Glass	Cor-Lam® Glass	Polyimide Glass
Acid Bath No. 1 (Unqualified)	483/1895 (23%)	20/350 (5.7%)	0/2081 (0.0%)
Acid Bath No. 2 (Qualified)	3/1733 (0.17%)	2/1033 (0.19%)	0/1019 (0.0%)
Pyro Bath (Qualified)	3/1830 (0.16%)	0/1394 (0.00%)	0/1724 (0.0%)

Table 6

- Polyimide glass is the superior MLB material.
- PTHs in polyimide-glass MLBs will not crack even when plated in a substandard bath.
- Post-plating baking of copper increases its ductility. (300 F for 2 hours)
- Both pyro- and acid-copper baths evaluated with proper controls and qualifications schedule will produce MLBs capable of passing thermal stress test per MIL-P-55110C. Must maintain control of additives, qualify bath on daily basis and establish schedule for carbon treatment of baths to remove excessive organic breakdown products.
- Tg can be used to determine amount of MLB polymerization.
- Epoxy glass is prone to cracking due to low Tg and high z-axis expansion.
- Preliminary evaluation of spiral contractometer and cyclic voltammeter show promise for monitoring organic additive concentration in copper plating bath.

Table 7

observed in epoxy-glass and Cor-Lam MLBs plated in qualified baths. A high incidence of cracked PTHs occurred in epoxy-glass MLBs plated in a nonqualified acid-copper bath.

Organics Monitored

A brief evaluation of the use of a spiral contractometer to measure the stresses of plated copper was made. Since the stresses can be related to the concentration of organic additives it is feasible to use this instrument to monitor the organic additive in the copper baths. Hughes will continue to evaluate this instrument to determine the viability of this technique.

Additionally, evaluation of the cyclic voltameter process developed at Rockwell Science Center yielded positive results in determining the concentration of the organic additive in the pyro-copper bath. A continuing evaluation of this process will be made to determine the viability of its use in controlling the organic additives in both the pyro- and the acid-copper plating baths. A summary of program conclusions is given in Table 7.

Reliability Provides Cost Benefits

The high glass transition temperature and low z-axis expansion values of polyimide-glass results in its capability to withstand the rigors of the thermal stress test as well as any temperature cycling tests without the attendant failures of cracked copper PTHs. The low probability of cracking in the copper PTHs will result in benefits that will more than pay for the higher cost of the polyimide-glass material.

Because of the promising results obtained in the preliminary evaluation of the spiral contractometer, a complete study should be made of this technique as a means of monitoring the organic additive in the acid and pyrophosphate baths. The instrument is relatively inexpensive (less than $800) and could be used throughout the industry—even by smaller companies.

Implementation Under Way

The processes developed in this program to produce MLBs with crack free copper PTHs were documented into a specification format and packaged into a handbook type of document for delivery to MICOM. A simplified visualization of this process is pictured in Figure 2. This specification includes the chemical makeups, operating limits of the process solutions and plating baths, full details of the process parameters, as well as QC steps required to ensure a reliable fabrication process. To demonstrate the viability of this fabrication process, six epoxy-glass and six polyimide-glass MLBs were made following the procedures outlined and delivered to MICOM for evaluation. These MLBs had a configuration similar to the boards plated in Phase III of this program.

As part of this program, Hughes has implemented the Sel-Rex acid-copper plating bath for production use at the Ground Systems Group facility in Fullerton, California. This bath, used in conjunction with the existing pyro-copper baths, was used to plate the MLBs used in Phase III of this program as well as to meet the production demands of manufacturing. To ensure crack-free copper PTHs on production boards, the acid- and pyro-baths were qualified daily prior to plating of any production boards. In addition, Hughes has implemented a postplating bake cycle of 300 F for a minimum of 2 hours to increase the ductility of the plated copper.

One of the most important results obtained in this program is recognition of the high reliability performance of polyimide-glass MLBs. Therefore, Hughes in the future will use polyimide-glass in place of epoxy-glass for all high reliability MLBs. They will continue to evaluate the spiral contractometer and the cyclic voltammeter. If one or both of these instrumental techniques are determined to be a viable means of monitoring the organic additive in the plating bath, then they will be put into production use.

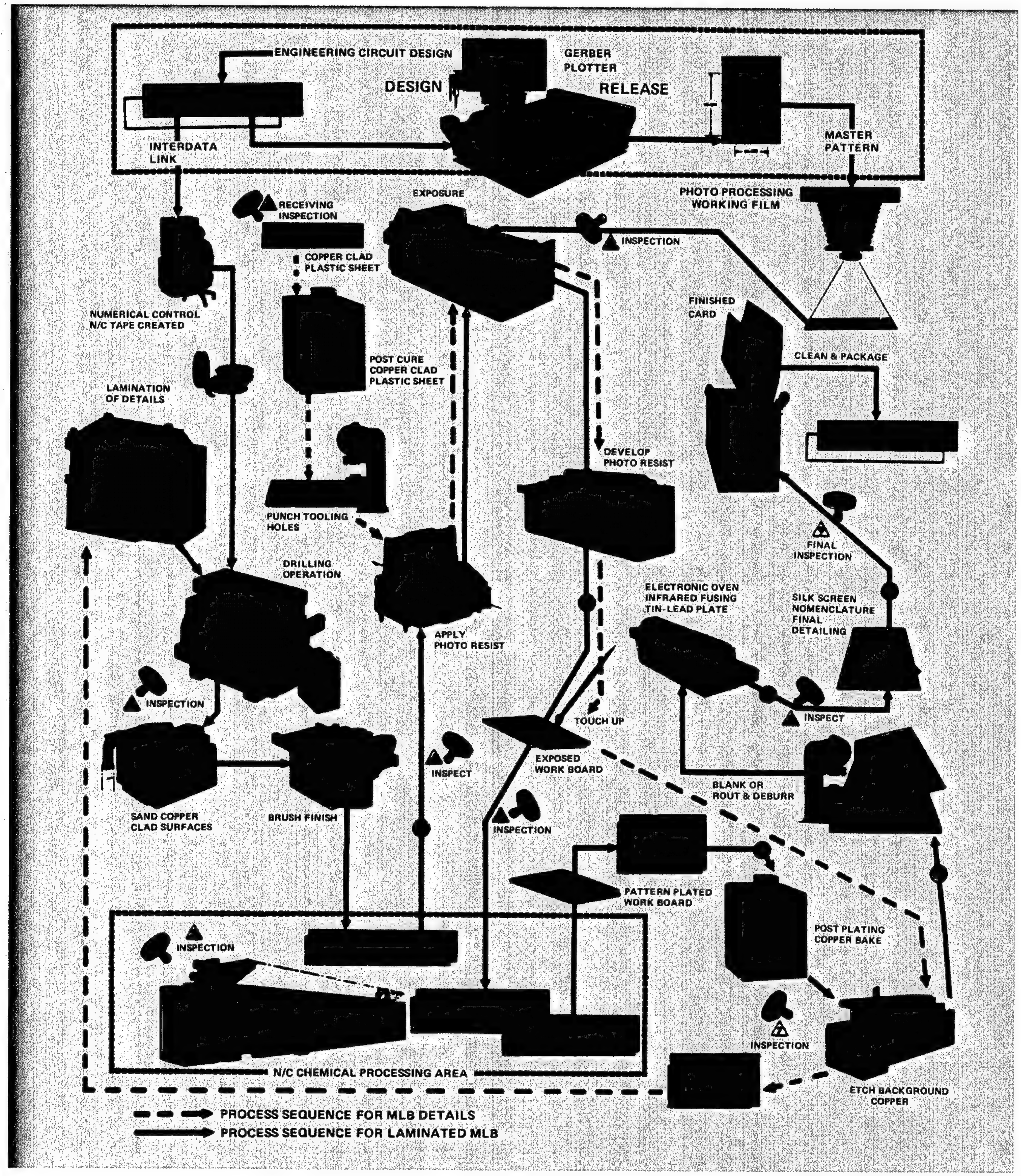
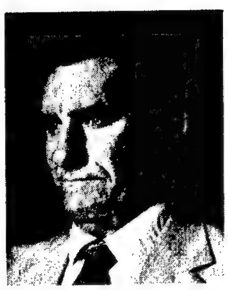

ENGINEERING CIRCUIT DESIGN
GERBER PLOTTER
DESIGN
RELEASE
INTERDATA LINK
MASTER PATTERN
PHOTO PROCESSING WORKING FILM
RECEIVING INSPECTION
EXPOSURE
INSPECTION
COPPER CLAD PLASTIC SHEET
NUMERICAL CONTROL N/C TAPE CREATED
FINISHED CARD
POST CURE COPPER CLAD PLASTIC SHEET
CLEAN & PACKAGE
LAMINATION OF DETAILS
DEVELOP PHOTO RESIST
PUNCH TOOLING HOLES
FINAL INSPECTION
DRILLING OPERATION
ELECTRONIC OVEN INFRARED FUSING TIN-LEAD PLATE
SILK SCREEN NOMENCLATURE FINAL DETAILING
APPLY PHOTO RESIST
INSPECTION
TOUCH UP
INSPECT
EXPOSED WORK BOARD
INSPECT
BLANK OR ROUT & DEBURR
SAND COPPER CLAD SURFACES
BRUSH FINISH
INSPECTION
PATTERN PLATED WORK BOARD
POST PLATING COPPER BAKE
INSPECTION
INSPECTION
N/C CHEMICAL PROCESSING AREA
ETCH BACKGROUND COPPER
PROCESS SEQUENCE FOR MLB DETAILS
PROCESS SEQUENCE FOR LAMINATED MLB

Figure 2

Best Method for Special Cases

Disposable Mandrels for Making Rocket Motors

SEIFORD F. SCHULTZ is a Research Engineer at the U.S. Army Missile Command, Redstone Arsenal, Alabama. Since receiving his B.S. in Mechanical Engineering in 1961 from Auburn University, he has worked on projects involving solid propellant and raw material processing. This project on development of a methodology for producing low cost disposable mandrels for which Mr. Schultz served as MICOM's monitor was conducted at the Huntsville Division of Thiokol Corporation under the direction of Thiokol Project Manager Glenn Webb, Jr. and Project Engineer Samuel Vance.



Throwaway plastic mandrels have been proven to be a more economical way than with reusable metal mandrels to produce propellant charges for small rocket motors that are manufactured in large numbers. Though not feasible for use with every type of propellant, the new technique often is the most practical means for many small motors on production runs of less than four years. These findings were the result of a manufacturing methods and technology project recently completed for the U.S. Army Missile Command by Thiokol Corporation.

In November, 1976, a program was begun to develop the manufacturing methods and technology required to reduce the cost of batch processing of small, high production motors such as those used in SEAS, Viper, and Free Flight Rockets (FFR) by the use of disposable (low cost throwaway) casting fixtures. The propellant used was quick cure HTPB.

By the end of 1977, comprehensive process engineering studies had been made to determine the recurring and nonrecurring costs associated with manufacturing 2.75 inch SEAS and Viper type rocket motors using both conventional reusable metal mandrels (or cores) and disposable (throwaway) plastic mandrels. In addition, extensive evaluations were conducted on candidate mandrel plastic materials as to cost, fabrication techniques, structural characteristics, compatibility with propellant, and dimensional control. The results of these studies and evaluations led to the following conclusions:

1. The cost of using the conventional reusable metal mandrel concept in SEAS and Viper motor applications is lower than the cost of using a throwaway disposable mandrel.

2. Based on the wealth of material technical data and cost information generated, there were indications of cost benefits from using "foamed" leave in place disposable mandrels in other motors.

These conclusions resulted in the program being redirected to the development of foamed mandrels for FFR type motor applications.

NOTE: This manufacturing technology project that was conducted by Thiokol Corporation was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Mr. Seiford Schultz, (205) 876-2568.

Five Major Tasks Undertaken

The basic program involved five major tasks:

1. Evaluation and selection of candidate disposable mandrel materials (including coatings and release agents) for use in SEAS and Viper motors

2. Validation of physical properties and formability of prime candidate materials

3. Laboratory compatibility testing of selected candidate materials (compatibility of mandrel materials/release agents/coatings/propellant)

4. Pull tests of candidate mandrels (with various materials/release agents and coatings)

5. Selection of a cost saving disposable mandrel casting fixture approach and establishment of recurring/nonrecurring costs of disposable versus reusable casting techniques.

The casting process and the design of the fixtures used to load solid propellant rocket motors are interrelated and must be based on many considerations. Factors that must be considered include ballistic performance requirements, motor case and hardware design, physical properties and handling characteristics of the propellant composition, production rate requirements and production quality, propellant ingredient and processing costs, propellant and ingredient sensitivity/toxicity characteristics, and motor manufacturing cost constraints (if known). With so many factors that have to be considered, there is no simple, straightforward procedure for selection of either a casting process or a casting fixture design; each job is a separate, new entity.

The mandrel itself has been "assigned" a number of functions in addition to the normal one of forming the propellant cavity during the propellant processing and propellant curing stages. At the propellant grains aft end, a "bulb" is provided which serves two functions. The first function is to reduce propellant grain stresses and strains at the nozzle to case wall interface region. The goal is to reduce stresses and strains below those in the main propellant bore so that propellant physical property requirements can be minimized (thus, cost reduced for a given performance level). The second function is to control the expansion and flow direction of the high velocity gases immediately ahead of the nozzle section. By doing so, the extent and uniformity of the throat erosion—thus, thrust alignment and impulse reproducibility—can be better controlled. (Figure 1).

The mandrel is also to serve as a nozzle environmental closure to eliminate the costs of a separate system. The closure needs to seal under 25 psi from either direction. It should be impervious to moisture. To accomplish this latter function, an aluminum foil disc can be added after mandrel fabrication.

The mandrel will also serve to support the propellant during transportation shock and vibration as it will also support the igniter lead wires to prevent vibration/shock induced failure.

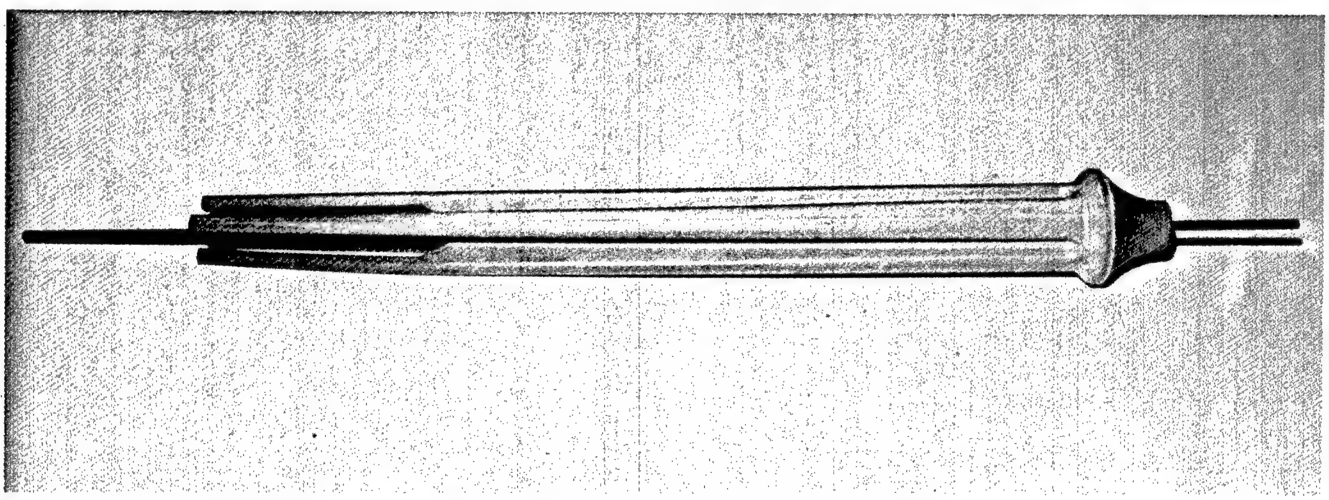


Figure 1. Polyurethane Foamed Mandrel

Spray-On Mold Release Agents Tested

Five mold release agents were purchased for testing to determine compatibility with propellant and mandrel materials as well as releasing qualities.

Material/Description

- MS-122 fluorocarbon, dry lubricant in aerosol spray can
- Durafilm CTF, compound TFE finish in aerosol spray can
- Poly-Lease 77 mold release, in aerosol spray can
- Floro-Glide, air dried Teflon in aerosol spray can
- 6075 Dry Fluorocarbon, lubricant and release agent in aerosol spray can

A number of the spray-on mold release agents were subjected to exploratatory evaluation tests using already available ambient cure HTPB propellant and polyurethane foam which were residual from another program. The tests were conducted by coating flat polyurethane foam samples with the release agents (using recommended manufacturer's procedures), casting cylinders of propellant against the coated samples, and, after propellant cure, conducting bond tests. Rather than acting as parting agents, the materials gave bond strengths in the order of 30 to 80 psi.

Application of the release agents using manufacturer's recommended procedures resulted in coatings which were too thin and ineffective. Four materials did appear to offer the most promise as mold release agents. Although high adhesion values were obtained with these four materials, failure did occur at the propellant-to-plastic bond line. Use of thicker coatings of the agents was explored during evaluation of the candidate mandrel materials.

Material Cost — A Prime Consideration

A broad array of materials for the mandrels themselves were examined, and then this was narrowed to eleven primary candidate materials. Basic material cost was a prime consideration for selection of a cost effective, disposable unit design. If several materials possess similar performance properties required by the application and have similar processing/manufacturing costs, then the one(s) with lowest material **cost per unit volume ($/cu. in.)** rather than **cost per unit weight ($/lb)** is clearly the choice.

However, the material with the advantage in cost per unit volume may lose this advantage when traded against a more costly, but higher performing (e.g., stronger) material which requires a proportionately smaller section size. This in turn can reduce the overall material amount and cost.

Samples of seven of the eleven candidate mandrel materials were ordered in sheet form for easy use for laboratory determinations of (1) propellant bond compatibility, (2) absorption of plasticizer/NHC (as contained in Viper propellant), (3) release agent coating compatibility, and (4) barrier requirements and compatibility. The seven materials were polyethylene—high density, polypropylene, polycarbonate (Lexan-Merlon), Polyphenylene oxide (Noryl), acetal (Celcon or Delrin), phenolic (G-10), and nylon.

Preliminary screening of these materials was conducted to determine their compatibility with various materials such as DOA plasticizer. NHC and IPDI also were evaluated with various mandrel coating materials and mold releases. In addition to the absorption test, tensile test specimens were made to verify the physical properties of the mandrel materials. Tensile stress ranged from 3,301 psi at ambient temperature for polyethylene to over 10,000 psi for acetal and ambient strain from 4.2% for polycarbonate to 31.4% for nylon.

The results of preliminary screening tests of candidate materials were as follows:

1. The MS-122 silicone release agent provided the lowest adhesion values.
2. The absorption of NHC (or DOA) for all the polymeric candidate core materials was lower than the maximum 0.5% limit set in a prior study. The tests showed that high density polyethylene, the container material used to ship the NHC burning rate catalyst, was the highest (0.3%) of the seven materials evaluated.
3. Uncoated nylon, polyethylene, polypropylene, and release coated phenolic showed the lowest adhesion to the two propellants.

The mandrel materials selected for the 2.75 inch program propellant were polypropylene, nylon, and a material not tested in this plan: PTMTN/PBT polyester. The mold releases selected were MS-122 with all mandrel materials and Crown 6075 with the nylon mandrel. These selections were based upon mandrel materials' physical properties, cost, and absorption properties. The mold release was selected for its low bond strength to propellant and absorption properties. (Figure 2).

The mandrel materials selected for the Viper propellant were G-10 phenolic and melamine. The melamine was not evaluated in this series of tests. The mold release selected was MS-122.

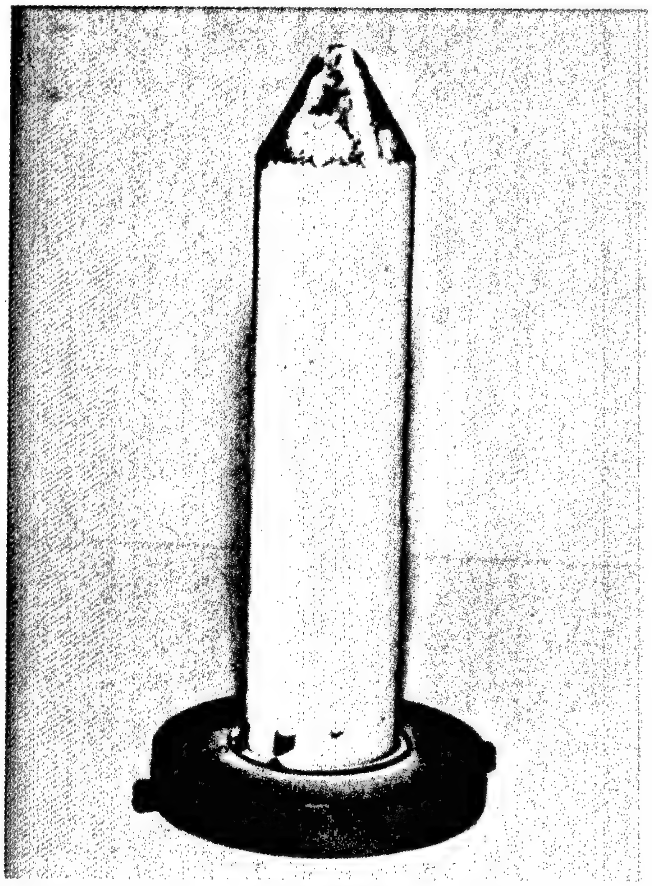


Figure 2. PTMT Core Sprayed With MS-122 After Extraction From Motor

Mandrels Pull Tested

The next step in evaluating candidate materials for disposable mandrels was to fabricate mandrels and use them in actual SEAS and Viper motor loadings. The force (lb/sq in. of propellant surface) required to extract the mandrels would be a good indication of their suitability. Considerable problems were encountered in finding a plastics vendor interested in manufacturing the needed 1.5 inch diameter cores for use in the mandrel pull tests.

After the motors were cured, arrangements were made to pull the cores using a strain gage load cell and recorder to record the force-time profile required to pull them. It had been intended to do the core pulling in a remotely operable Instron testing machine, using a constant cross head speed. Further evaluation of this operation indicated that it would be extremely difficult and expensive to provide a means of sufficiently restraining the motor assembly to meet safety requirements.

Core pulling was therefore done in the standard small motor core pulling machine. This unit uses a long stroke hydraulic cylinder to apply force to the core. The force is controlled in magnitude by controlling the hydraulic pressure (Figures 3, 4, and 5).

A strain gage load cell was provided with approximate fittings to allow its insertion between the rod and the extraction wrench. The cell was excited by a remotely located bridge supply/amplifier connected to a linear strip chart recorder. Initially, a 500 pound cell calibrated to give one inch displacement for 50 pounds of load was used. Subsequently, a 1000 pound cell calibrated for 100 pounds per inch of chart displacement had to be used.

Silicon Significantly Reduced Pulling Forces

The use of IMS release agent spray over Teflon coated metal mandrels for the Viper propellant had been recommended by MICOM. A significant reduction in pulling forces had been expected, but not quite as dramatic a reduction as actually experienced. It leads to the question of how effective the IMS spray would be on plastic cores. The MS-122 silicone release agent spray significantly reduced the pulling forces involved for all three of the plastic cores used with the SEAS type propellant. However, it did not prevent adhesion of the propellant to the nylon cores and the subsequent damage to the propellant grains. The fact that both the cores and the grains had sticky surfaces leads to the conclusion that the nylon itself interfered with the cure of the propellant binder system. The PTMT cores are marginally satisfactory **if** coated with a suitable mold release agent; the relatively high pulling forces with MS-122 are not that different from those for polypropylene, with or without the

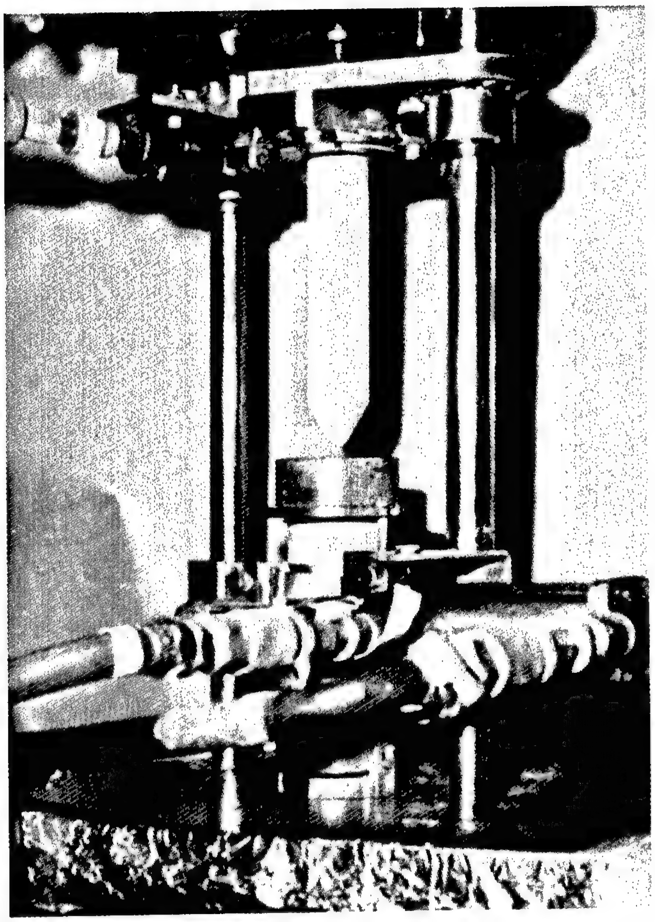


Figure 3. PTMT Core Installed in Remotely Operable Insertion Machine

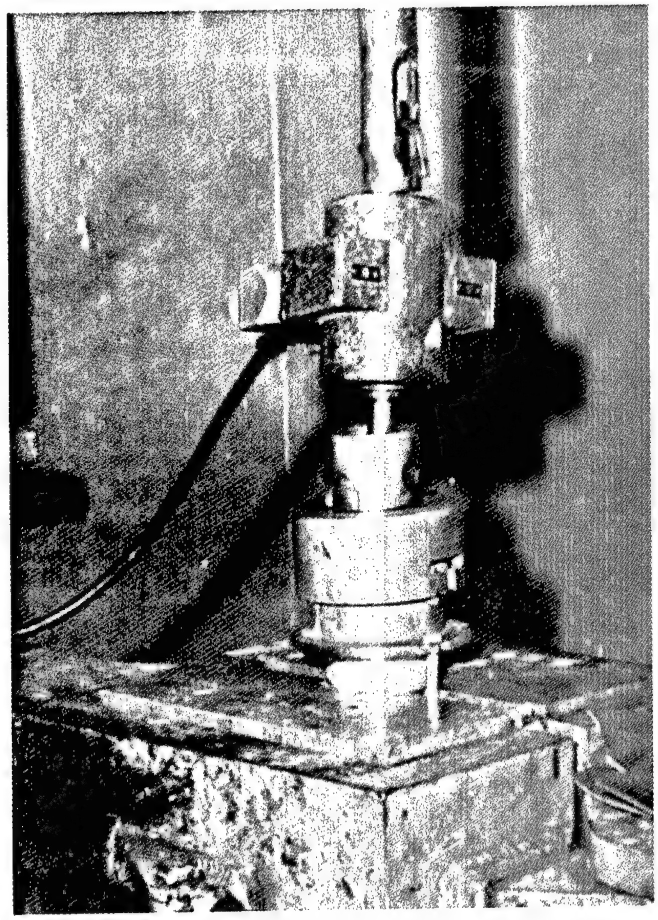


Figure 4. Core Pulling Equipment Connected to Motor

MS-122 release agent. One of the PTMT cores split open during propellant cure, indicating possibly less than satisfactory physical characteristics.

TX395 motors were then static tested to determine if there are differences in ignition or motor ballistic performance due to differences in mandrel materials and release agents used in casting the motors.

Viper Propellant and MS-122 Don't Mix

Motors containing SEAS type propellant showed no significant differences in operation caused by the use of different mandrel materials. However, data from motors containing Viper propellant tell quite another story. These motors—cast using phenolic mandrels coated with MS-122 release agent (the only combination which appeared to be usable in earlier screening tests)—had twice the delay times as those motors cast with either coated or uncoated metal mandrels. Also, ignition rise rates were lower. Thus, there must have been some interaction between the release agent/mandrel material and the Viper propellant that affected ignition of the motor. Such an interaction is unacceptable and would preclude the use of plastic mandrels/release agents for motors containing Viper propellant.

To Summarize Thus Far

To summarize, econometrics and engineering parameters for seven primary mandrel manufacturing methods

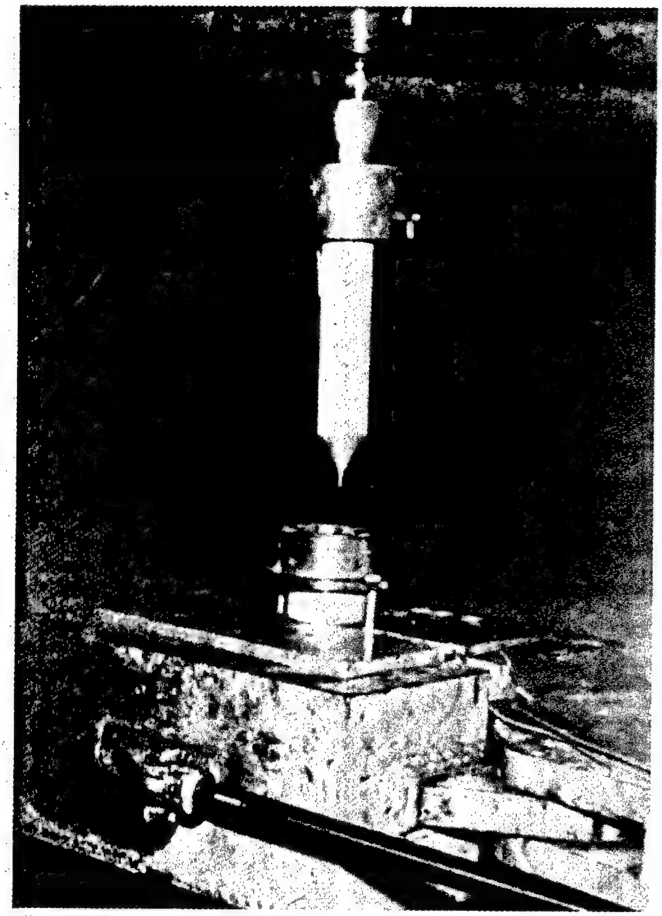


Figure 5. Core After Removal From Motor

were evaluated to determine the cost of a single use disposable mandrel for SEAS and Viper motors.

In conducting the study which led to the mandrel cost estimate, full advantage was taken of the prototype mandrel/motor experimental work done previously. Briefly, four candidate disposable materials were fabricated into 1.5 x 5 inch motor core mandrels, then 40 motors of two varieties and also four lots of propellant compositions were cast. By taking an array of measurements of TFE coated steel baseline cores and the four types of plastic cores, comparisons were first made with the mold and part shrinkage determined. From measurements of the cores, 16 units of each material, and of the motor base (ID), the part variability was established. The cost information from suppliers of seven various fabrication methods was compiled for a comprehensive unit production cost estimate. Where vendor (jobber/supplier) quotes were not attainable or not solicited, engineering estimates of production unit costs were made.

From the detailed investigation of materials, manufacturing feasibility, and costs, it is concluded that a satisfactory single use disposable mandrel could be fabricated from a polypropylene material by a melt processable structural foam process for the SEAS motor. (Figure 6). The full acceptability of the unit is still contingent upon a complete assessment of the motor ballistic envelope as influenced by part dimensional variability. This core mandrel would cost between $0.80 and $0.90 per unit in minimum lots of 600,000.

The VIPER core was not found to be producible by any of the high volume production methods investigated. The

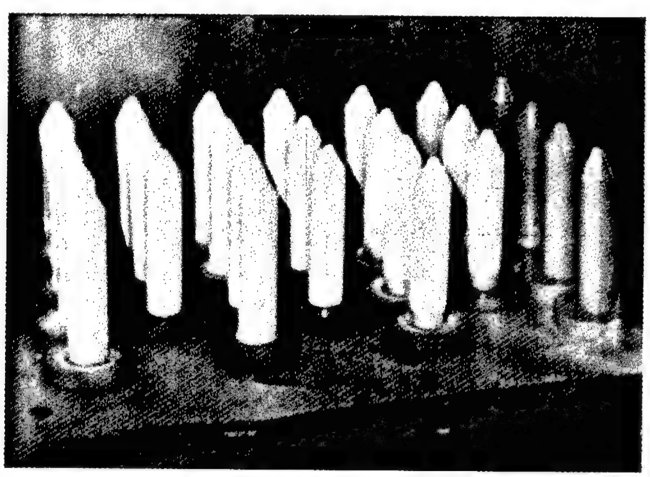


Figure 6. Cores Awaiting Insertion into SEAS Propellant Motors

primary reasons were the requirement for close dimensional control and the inherent problem of removal of a cast or molded part from a die/mold which allows no draft. Only extensive redesign of the core or investment of point development has any prospects for fabrication of a high production core in the $1.00 copy range; and this is not competitive with a conventional reusable approach.

The above mandrel cost estimates are based on extensive evaluation of the seven mandrel manufacturing methods: melt processable structural foam; zinc die casting; compression, transfer, or injection molded thermosets; multicomponent foam molding (expanding foam); thermoplastic injection molding; thermoplastic profile extrusion; and thermoplastic extrusion blow molding.

Original Effort Reviewed

The previously discussed process engineering studies and cost estimates for SEAS and Viper rocket motors led to the following conclusions:

1. There is evidence that the cost of using the conventional reusable metal mandrel concept in SEAS and Viper motor applications is lower than the cost of using a throwaway disposable mandrel. The recurring and nonrecurring cost of using a metal mandrel is estimated to be $0.65. This is less than half the cost of a $1.39 hard disoposable mandrel.

2. Based on the wealth of material technical data and cost information generated on the program, there are indications of cost benefits from using "foamed" leave in place disposable mandrels in other motors.

Based on these conclusions, the program scope of work was redirected by contract change to the development of foamed mandrels for free flight rocket type motor applications.

Redirected Program

The first step in pursuing the redirected program (which was begun in April, 1978) of evaluating foamed, leave in place mandrels for FFR type motor applications was to formulate a design concept of an FFR motor. Using this concept, a foamed mandrel design was generated.

The following features were incorporated in the mandrel/motor design:

- The preliminary configuration of the GFE case to be fabricated by McDonnell-Douglas/Titusville was used.

- A stress relief bulb was incorporated at the propellant nozzle interface.

- The stress relief bulb also served to control the expansion of propellant gases at the grain aft end to obtain more uniform and lower nozzle erosion.

- The mandrel formed the nozzle environmental closure.

- A steel rod used to center the core and prevent warpage during cure provided a hole through the mandrel igniter leadwire for support.

The predicted performance (thrust and pressure) of the motor 70 F was: maximum thrust, 7543 lbf; maximum pressure, 2067 psia; the motor load 54.5 lbm of propellant. Total impulse was 13,200 lb/sec.

The conclusions reached from the data obtained from this evaluation are as follows:

1. Polyurethane foam mandrel material will absorb NHC and DOA.

2. Polyurethane foam will expand 5-10% when heated from room temperature to 170 F, depending upon density and direction of the material.

3. The foam mandrel materials will increase in weight (absorption of moisture) at 0 F and lose weight at +170 F.

4. The foam mandrel material will blister and warp at 170 F.

5. Tensile stress for the 7 lb/cu ft density material is 222 psi and 70 psi for the 5 lb/cu ft material. Strain is approximately the same for both materials—1.8 and 1.4%, respectively.

6. TP-H8266 propellant bonds well to the foam mandrel material (polyurethane with no mold release).

7. The mold release evaluted appears to be relatively ineffective as a propellant release agent to polyurethane. The adhesion failures were in the propellant (32 psi) or bond and propellant at 50-60 psi.

8. Based on Conclusions 1 (absorption tests) and 6 (propellant bond tests), polyurethane used against propellant as a mandrel material should be coated with a release agent and/or barrier material.

Bubble/Blister Problem Eliminated

Results of dimensionally inspecting the first two polyurethane foamed mandrels were compared with those from the metal mandrel used as a mold former.

All of the first twenty prototype mandrels had varying degrees of subsurface voids or bubbles. Some exhibited voids which opened to the surface. Also, the four head end extensions on some of the mandrels were twisted or warped out of shape. However, six mandrels with especially good workmanship/appearance/quality were selected for use in the loading of TX707 motors. The remaining mandrels were acceptable for evaluation of storage life, bakeout tests, etc.

Information concerning the generally poor quality of the mandrels was passed on to the fabricator, and the quality of the fifty "production run" mandrels was considerably better than the initial prototype group. The former end of the mandrel were straight and untwisted.

Process engineering studies to compare costs of loading motors with foamed, leave in place disposable mandrels versus removable, reusable mandrels were conducted.

Costs Analyzed

A methodology for developing the recurring and nonrecurring costs for comparing the use of reusable hard tooling with the use of disposable plastic tooling was established during the original program effort. It was used to compare the costs for both the 2.75 inch and the Viper rocket motor concepts. A similar approach was used to evaluate the cost of using "hard" or reusable tooling for the FFR motor concept.

Summing up the various recurring cost increments—from fabrication of the core bulbs and wire supports, core refurbishment operations, and specific motor manufacturing labor operations, the following results are evident.

Nominal Yearly Production Rate	Nominal Uses Before Refurbishment	Net Recurring Cost Per Motor Produced
50,000	20	$6.8912
50,000	60	$6.4778
100,000	20	$7.1622
100,000	60	$6.5068

Six Motors Loaded

Six TX707 motors were successfully loaded from a 50 gallon mix of TP-H8266 propellant. Radiographic inspection of the motors revealed several small voids randomly scattered in each motor, but the voids are of no consequence relative to motor performance.

A single TX707 motor had been loaded on another program and had encountered two problems: (1) the polyethylene grain former sleeve had collapsed during propellant cure and was oval in cross section rather than circular and (2) propellant had bonded to two foamed core tips for about half the length of the motor. Both problems were eliminated from the 50 gallon loading by (1) filling the grain former sleeves with silicone rubber and (2) applying an extra heavy coating of mold release agent to the foamed mandrels.

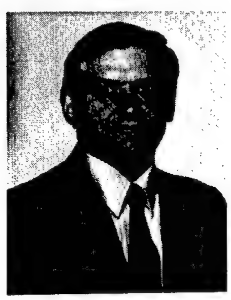
The six loaded cases were prepared for assembly and delivered to MICOM, along with eighteen of the "production run" foamed mandrels.

Disposable Units for Short Runs

The net per use cost for reusable tooling, as compared to the procurement cost per leave in place foam core, varies from a low of about $7.30 to over $14.20, depending upon the conditions attainable and/or contracted for. Thus, using a leave in place (disposable) polyurethane foamed mandrel with unit costs of $7.60, $7.10, and $6.60 for quantities of 10,000 20,000, and 50,000 units per year, respectively (exclusive of support rod costs), is a less expensive motor loading concept than reusable tooling for short periods of production (four years or less). The net per use cost for reusable tooling approaches the unit cost for disposable mandrels at the longer production periods. Thus, the leave in place foam concept may be the lowest cost approach for short periods of production and is definitely a viable alternate to the frequently used rope and rubber grain former approach.

Hermetic Chips Carry Load

MM&T of Large Scale Hybrid Microcircuits



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The purpose of this Manufacturing Methods and Technology effort between Martin Marietta and the U.S. Army Missile Command was to develop the manufacturing technology necessary to design, fabricate, test, and rework large scale hybrid (LSH) microcircuits with cost effective yields and to evaluate the capability of such assemblies to withstand extreme environments.

Large scale hybrid techniques were combined with hermetic chip carriers to produce an assembly which directly replaces standard printed circuit board assemblies used in missile environments. The manufacturing methods and technology described here were used to produce a 2.5 x 3.5 inch semihermetic hybrid assembly with a ceramic substrate and an epoxy-graphite backplate. The resulting data show that such an assembly can withstand missile electronics environments but is marginal in comparison to cannon launched projectile qualifications requirements. Process controls including substrate electrical testing, hermetic chip carrier screening, and measurements on test pieces were implemented to produce yields sufficient to achieve a 30 percent cost savings over conventional construction.

LSH microcircuits for the effort were defined as microcircuits having a substrate area greater than 4.5 square inches, requiring a multilayer thick film substrate network and containing a combination of active and passive devices. The LSH was to be constructed so that it would successfully pass military screening tests. The three major phases of this work were:

1. **The Basic Phase,** which established the design, materials, and packaging concept.

2. **The Option Phase, Pilot Production,** which consisted of fabricating 60 assemblies in a production environment using normal documentation and procedures.

3. **The Option Phase, Environmental Testing,** which dealt with verifying material selection with regard to severe environmental stresses.

NOTE: This manufacturing technology project that was conducted by Martin Marietta was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Project Engineer is Mr. Paul Wanko (205) 876-7097.

Present Technology Evaluation

The First or Basic Phase of the contract was to determine the extent of LSH techniques being used in the industry and to develop a design which would be suitable for implementation on some military system under development or in production. This was done through an industry survey followed by an internal review of candidate circuits appropriate for LSH techniques.

An inplant survey of major high reliability military hybrid suppliers was conducted to establish a baseline of yield and cost information affecting design guidelines, parts and materials qualification, substrate fabrication processes and procedures, assembly processes and procedures, test and fault isolation techniques, and rework. Eleven companies were then visited and the subject of large scale hybrid (LSH) microcircuits was discussed. The general opinion was that LSH techniques are feasible, the need is selective, and packaging approach and die connection technique is dependent on the circuit to be fabricated and on the production quantities. Most of the companies were fabricating hybrids with the technique of chip and wire on a ceramic substrate contained in a metal sealed package. Only two of the companies were using or planning to use leadless hermetic packages on a ceramic substrate located on another assembly.

Only one company was in production, and only one commercial company had true production plans. In small quantities, that cost and yield information was not available and inconsequential as far as overall program importance. Consequently, the information received as to what was being fabricated was much more valuable. Fabrication characteristics that were common to the companies and considered to be of prime importance are:

1. Ceramic substrates primarily used
2. Six conductive layers maximum
3. Substrate material and dielectric inks critical
4. Ten mil line x 10 mil spacing, 15 mil via, common limit: 6-7 mil spacing and 10 mil via
5. Maximum active chip packaging density of 11 chips per square inch of substrate
6. Active chip testing prior to installation limited to incoming inspection sampling—one company tested each chip
7. No pre-lid or pre-seal burn-in
8. No complete MIL-STD-883B tests performed
9. Typical build quantities have a rebuild cycle of several months.

No company visited or contacted by phone was fabricating or anticipated to be fabricating large scale hybrid microcircuits in production quantities.

Design Criteria, Hardware, and Tradeoffs

Since the inplant survey and telephone inquiries revealed the fabrication of an LSH microcircuit by only one company and their design did not have weight limitations or undergo screening tests, it is obvious that there was no baseline for yield or cost information. Therefore, the approach taken during this effort was to develop a technology for large scale microcircuits that would consider the techniques and characteristics of thick film, components, layout, packaging, fabrication, test, rework, cost, and yield. The technology developed is generally applicable for industry use.

The baseline from which the technology design and fabrication emerged was established as being common industry techniques determined during the survey, combined with generally accepted standard hybrid design guidelines. These factors were then modified with a final assembly which is not a sealed metal package but an alumina substrate containing screen printed thick film resistors and chip capacitors and hermetic chip carriers attached by reflow soldering. A new quality assurance screening plan was generated with the requirements of MIL-STD883B serving as a baseline. The assembly testing plan required the screening of each ceramic chip carrier with the appropriate die installed and then the performing of high, low, and ambient temperature and temperature cycling tests on each completed assembly.

The verification unit was a spin and precision assembly under development by Martin Marietta on the Navy Guided Projectile program. The circuit was reviewed in depth and accepted by both Martin Marietta and MICOM as the verification circuit. The circuit contains both analog and digital functions implemented with discrete resistor, capacitors and transistor, monolithic bipolar analog devices, and C-MOS logic devices. Die size varies from an individual transistor to standard C-MOS logic and ultimately to an LSI chip.

After reviewing the requirements of the verification hardware as related to the design baseline and overall task requirements, there were several areas in which tradeoffs were necessary.

- The use of layout experience and consideration of die size and parts count of the verification circuit indicated that the necessary conductive layers were half of the design limit. Although fabrication and yield experience suggest that a minimum number of layers be used, minimum conductor spacing and proper solder pad area for the chip carriers must be provided. Considering this and the unknown sensitivity of the circuit to coupling capacitance, the layout was made with two conductor layers.

- Maintaining the Martin Marietta standard hybrid design practice of locating conductor paths between component solder pads was of importance. However, the size of the solder pad necessary for proper attachment of the carriers was not known. If the pad size were provided as for capacitors with pad size width and length extending beyond component end termination, the resultant carrier pad size would violate design guidelines regarding minimum conductor spacing. Chip carrier pad width was provided as 15 mils or 5 mils larger than normal metallization. Pad length provided was 10 mils added to the interior of the carrier lead pattern and 20 mils to the exterior. In this manner, both the carrier mounting guidelines and the use of conductors in between pads was maintained.

- Since the final assembly will essentially be an open substrate (no cover), selection of silver, gold, copper, or other material for the metallization was important. The choice was narrowed to silver, gold, palladium silver, and platinum gold. Gold and platinum gold were selected because of ability to rework, less stringent solder conditions, and less migration potential. Gold was used for all interconnects and platinum gold for solder pads and associated short runs.

- A tin/lead/silver composition had been used with good success in solder reflow processing. Indium/lead was also considered but rejected because of increased solder balling, less rework capability, and lack of acceptable supporting data. The Multicore finally chosen is Sn62, Pb36, Ag2.

- Part of the approach in the technology development is the extensive testing performed at the component level and the resultant anticipated increase in final assembly yield. The packaging concept and component testing inherently limits assembly rework to chip carrier or chip capacitor replacement. As there are several types of carrier removal tools available from industry, the only rework problem was considered to be in determining during test which chip carrier needed to be replaced. It was conceived that through the use of screened thick film resistors, completely pretested chip carriers and a detailed test specification, there would not be a need for test points.

- A glass overcoat was provided over all areas except solder pads to prevent solder balls occurring during reflow from damaging the metallization to prevent molten solder from leaching the gold interconnect.

- A glass overcoat was provided over all areas except solder pads to prevent solder balls occurring during reflow from damaging the metallization to prevent molten solder from leaching the gold interconnect, and to assist sealing of the assembly during environmental exposure. The need for general conformal coating to prevent damage during environmental exposure was anticipated and evaluated during Option Phase testing.

- The interchangeability requirement placed on the verification hardware required a detailed material investigation. The material selected had to be compatible with ceramic to the extent that it could be used for structural support when the combined assembly is mounted in the end item as well as end item exposure to system operational conditions during the mission. All imposed requirements could be met best by employing a graphite-epoxy procured in layer form. The epoxy is laid up in an orthogonal manner into a trapezoidal shape of the dimensions required to meet the functional requirements.

Combining standard hybrid design and fabrication guidelines with the above tradeoffs and the desired technology goal resulted in the flow diagrams. The newly designed LSH microcircuit is composed of four types of components: ceramic substrate assembly, chip capacitors, hermetic chip carrier (HCC) assemblies, and connective pins. The three fabrication operations: thick film process-

ing, chip carrier assembly, and LSH assembly are fabricated in the manner indicated by their respective flow diagrams.

Initial Evaluation

Since in most instances the LSH design employs a technology the same as or close to existing standard hybrid design, there was a limited number of areas in which new process development was necessary. These areas include the soldering of capacitors and chip carriers to the large ceramic substrate, and the solder/thick film metallization interaction during environmental stresses. Major items whose effect on the soldering operation was unknown include emulsion thickness, screen mesh size, solder composition, size of solder pad relative to chip carrier footprint, solder/thick film interaction, required fillet, and pull down effect on the chip carrier during soldering.

The process development was started with the fabrication of sample LSH substrates utilizing standard processes and materials and a Presco Model GP-885 thick film screen printer. Tin/lead/silver (62/36/2) solder paste was screened on, using a Weltek Model 22 screen printer, a 220 wire/inch screen mesh, and 1 mil emulsion. Each solder pad was burnished to remove oxygen contamination and the substrate assembly cleaned with freon. Nontinned capacitors and dummy chip carriers were placed onto the appropriate solder pads by hand with the aid of a Bausch and Lomb microscope. The LSH was then placed on a Browne LR-6 linear reflow soldering system. With preheat and reflow temperatures set at 190 C and 240 C, respectively, the exhaust fan off and the belt speed set for 12 inch travel in 28 seconds, solder reflow was performed.

The resulting solder connections on each of the capacitors and chip carriers were inspected regarding wetting, fillets, cracks, leaching, solder balling, component alignment, and amount of solder applied. The initial values of screen mesh and emulsion thickness were found to be unacceptable. There was little or no solder filleting; each component appeared to have been merely stuck down rather than soldered. Many chip carriers did not appear to have been properly aligned, as shown in Figure 1. There was a general lack of solder on the entire assembly.

The first modification was to pre-tin all components by using a standard solder coating process in which each part is manually dipped into a solder pot to a depth to wet the desired area, removed, rinsed in AP-20, and allowed to air dry. Pre-tinned parts were then located on new substrate samples with the solder paste screened as before.

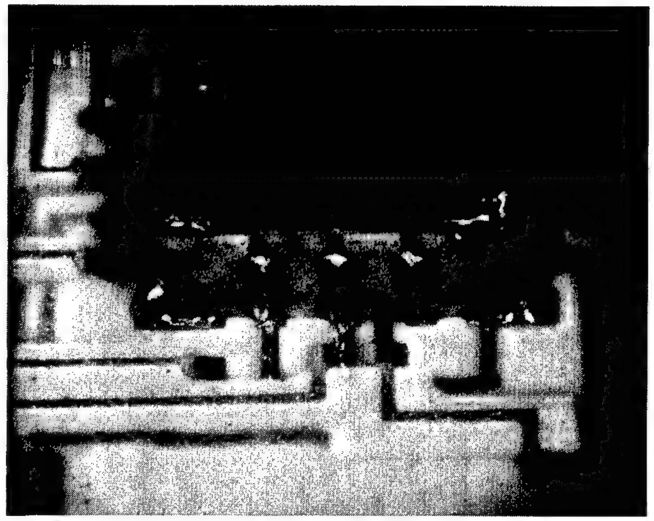


Figure 1

The solder was reflowed again using the Brown belt machine operating as before. A great improvement was observed in that there was definite solder filleting on all components. Each component appeared to be soldered down and chip carriers were generally aligned (Figures 2 and 3). However, there appeared to be a generally insufficient amount of solder on the components and, in some cases, poor wetting action.

The next few modifications consisted of changing emulsion and/or screen mesh size and repeating the assembly procedure. Finally, a combination of 105 wire/inch screen mesh and 2 mil emulsion produced the best results. Component alignment was found to be a delicate operation, but if care is taken during manual placement, they align themselves and are pulled down tight to the substrate during reflow.

Several assemblies were reflowed using this technique with very consistent results. Typically, two or three chip carriers per assembly needed touchup on one to three pins. For the 18 chip carriers and 11 capacitors, that means there were approximately six touchups necessary out of 418 possibles (1.5 percent). Solder balling was almost nonexistent. Leaching did not occur and cracks were not observable. Fillets and solder buildup was good. Wetting action was not as good as desired and was noted as a problem to be addressed in assembly testing. Further refinement of the reflow soldering technique occurred during the Option Phase. Evaluation of the technology developed at this point was performed by fabricating and then testing complete LSH assemblies containing electrically good components.

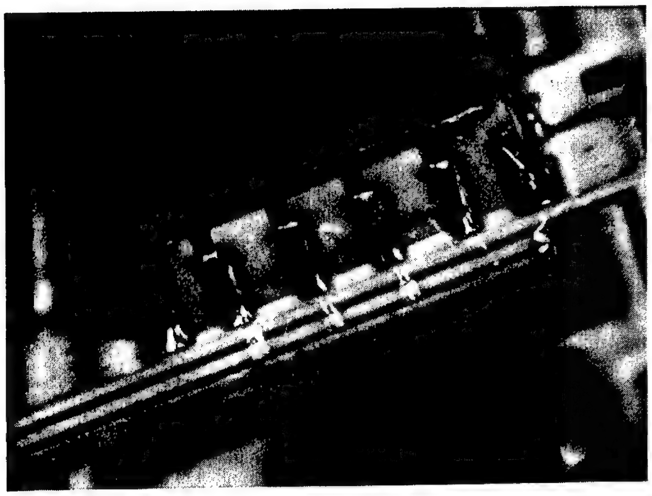


Figure 2

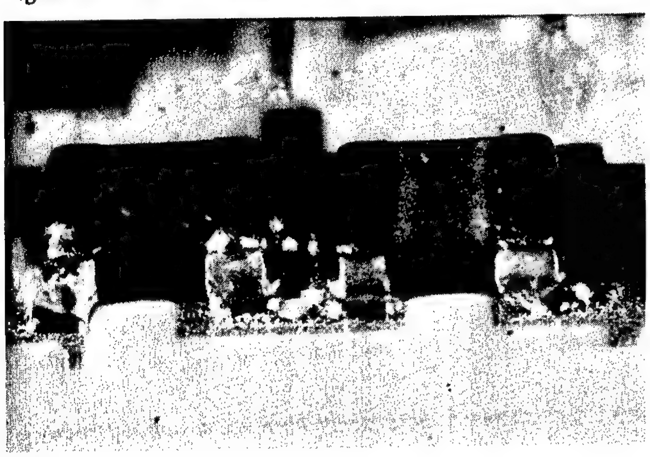


Figure 3

Fabrication and Failure Analysis

Two of the Navy GP LSH microcircuits were fabricated and delivered to failure analysis for critique. The failure analysis personnel were asked to comment on the solder connections of each component. Since there were no established guidelines to follow, their response was to be OK, acceptable, needs touchup, or reject. The definition of each response being as follows: OK—good; acceptable—meets minimum standards; needs touchup—doesn't quite meet minimum standards; and reject—requires complete resolder. Of the 24 capacitors so inspected, 19 were found to be OK, 2 to be acceptable, and 3 to need touchup, for an 88 percent accept rate and a 0 percent reject rate. Of the 37 chip carriers so inspected, 7 were found to be OK, 14 to be acceptable, 14 to need touchup, and 1 to be rejected, for a 58 percent accept rate and a 3 percent reject rate. This rejection was due to one chip carrier being cocked at an angle to the substrate, indicating mishandling immediately prior to reflow. Most of the needs touchup and the reject ratings occurred on the same substrate, indicating some malfunction during the solder screening or reflow.

The assembly with the OK ratings was delivered to test for evaluation. The other assembly was delivered back to the fabrication area for independent appraisal. The findings that resulted included the same chip carrier being cocked but only two chip carriers needing touchup. These carriers were touched up and the assembly delivered to the test department. A pictorial view of a typical LSH microcircuit is shown in Figure 4.

Electrical tests verified the correctness of the substrate metallization, vias, and pin connections as well as overall operation of the assembly. At this point, the remaining eight LSH microcircuits were fabricated, inspected, reworked as necessary, and delivered to the test department for further evaluation.

After completion of the respective component tests (inspections), each of the good components were delivered to stock and later pulled in the appropriate quantities for fabrication of the 10 LSH assemblies. Since the circuit implemented into LSH format was to have been interchangeable with the Navy GP spin and precession assembly built by Martin Marietta using conventional techniques, the test fixture and test specification used to

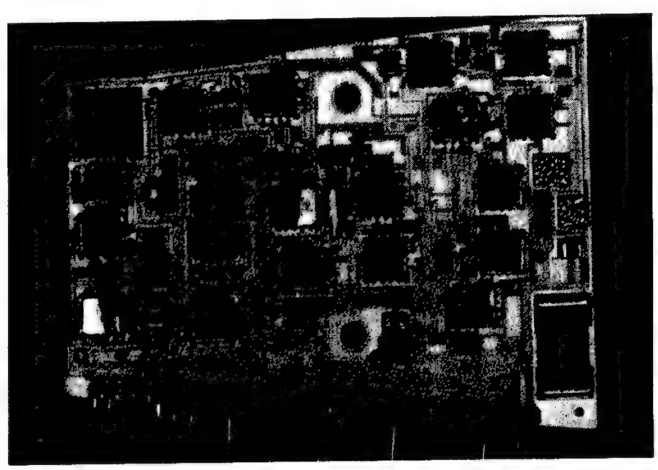


Figure 4

check out the conventional assembly was utilized to check out its LSH counterpart.

Four assemblies passed all electrical tests at +25 C, -55 C, and +125 C. Of the six assemblies which failed initial electricals, four were attributed to active device failure and two were due to substrate network defects. All assemblies that failed were reworked successfully.

Nine Points to Improve Manufacturing and Yield

Fabrication of the 10 LSH assemblies revealed several areas for consideration of design modifications to improve manufacturability and yield. These areas were as follows:

1. Recheck and remove glass overcoat near solder pads of the chip carriers. In some cases the overcoat extends too close to the pad resulting in difficulty in carrier alignment and the possibility of insufficient solder application during paste screening.

2. Rotate capacitors with common connections from end to end layout to a side by side configuration. This would permit better probing and solder reflow action. Move capacitors away from resistors. The expected results would be the same as the side by side orientation of capacitors.

3. Epoxy external pins on both sides of the substrate, not just on the back side. These pins are small, made of soft metal and can be easily ripped off the assembly during the application or removal from test fixtures. The added epoxy will insure the rigidity of the connection thus limiting damage to the pins and not to metallization.

4. Consider the use of pre-tinned capacitors.

5. Evaluate the use of a metal mask or other technique to increase the amount of solder available for reflow during LSH assembly.

6. Provide test points on the assembly. Although pre-testing the chip carriers reduced the trouble shooting time, the circuit operating complexity was more involved than anticipated and even with modularization via the carrier approach it was impossible to completely localize the cause of improper assembly operation. Addition of appropriate test points would permit detection of defective components but would not permit quick resolution of such problems as shorts or open metallization in interior interconnect. These problems could be resolved by introducing substrate tests during fabrication of the substrate layers if it could be shown to be cost effective.

7. Institute substrate electrical tests. Of the seven total failures during the LSH assembly phase, two were directly attributable to substrate errors. These include an open metallization run and an undesired short between two metallization runs. Although limited visual inspection was performed on each, the problems were so small that they were not detectable unless specifically looked for. At least one of these could have been found with an electrical test. Such tests were partially instituted during the pilot production.

8. Continue testing of chip carrier prior to installation on the substrate assembly. Receiving inspection acceptance tests on a sample lot basis was shown to be valid, as only two of the appropriate chips assembled into carriers failed during LSH assembly tests for a 2.3 percent reject rate which indicated that screening prior to LSH assembly should be more extensive.

9. Continue cost analysis as technology development proceeds. Preliminary cost analysis indicates that a savings of approximately 30 percent can be obtained on production quantities of 200 units when the LSH technique is utilized versus the existing conventional packaging.

Pilot Run Finalizes Criteria

The Second, or Option Phase, of the contract consisted of a pilot production run of 60 LSH assemblies to finalize the criteria for fabrication of full production hardware and to determine the actual labor input such that the cost of the LSH technique could be demonstrated. In addition, test assemblies were fabricated to determine the environmentally safe operating region with and without the use of backplate material.

Areas of interest identified previously were considered for design modification with the following actions:

- The glass overcoat was adjusted through the use of a new mask to prevent tolerance buildup from causing obstruction of the solder pads.

- Relayout of capacitors and resistors was considered but not initiated due to limited funds for redesign during the Option phase.

- The use of epoxy overcoat on both sides of the edge pins was instituted for increased mechanical strength required for test and burn-in insertions on the LSH assembly.

- Pre-tinned capacitor chips were used for some test assemblies and approximately 35 percent of the pilot production in an attempt to achieve better solder filleting. Pre-tinned was discontinued after the results from fabrication of test assemblies showed less solder leaching of the Pt-Au conductor pads and Pd-Ag end bands with non-tinned parts.

- An evaluation of 5 mil metal masks and procedural changes with 2 mil emulsion masks was made to increase the thickness of solder paste for reflow.

- Testing of substrate networks for open and shorts was found to be a critical factor for increasing assembly yields.

- Other variations which would be advantageous on larger volumes might include doing continuity and shorting tests prior to overglazing and using automated equipment such as the DITMACO board testers prior to releasing substrate networks for reflow solder assembly.

- HCC screening was increased.

Modifications Increase Yields

Process improvements were made to increase yields and to transition to production equipment from the prototype equipment used during the basic phase. Resistor trimming of substrate networks was shifted to automated equipment with programs written for the ESI 44 laser trimmer. Figure 5 shows a substrate with one of three probe rings in place. Due to the circuit layout, it was necessary to use three different rings to prevent probes from blocking the laser beam.

Hermetic chip carrier processing incorporated 100 percent nondestructive bond pull testing and increased stress screening to reduce final assembly yield loss. Lead bonding was done on an automated bonder using 1.3 mil gold wire and tested to 2.5 gram force in accordance with Method 2023 of MIL-STD-883. Screening consisted of stabilization bake, temperature cycling, hermeticity, and full electrical parameters at -55 C, 25 C, and 125 C using the Tektronix 3260 tester. This testing was in addition to the normal incoming chip inspection and sample testing.

Reflow solder assembly was done on a Browne AR-7 three zone belt reflow machine which provided greater control of the preheating profile. Solder paste was applied using a Weltek printer with a double printing technique which was off contact on the second pass. This resulted in a minimum of 0.008 inch of wet solder paste which, when combined with the pre-tinned HCCs, gave acceptable joints.

Standard Equipment Saves Money

Equipment used in this work was all standard, readily available, and typical of that used by many microelectronic manufacturers. It was intended that careful material selection and process controls would produce a product which could be manufactured on a prompt response basis to meet specified environmental levels.

Since all standard equipment was used, there was no requirement for unique tooling fixtures or equipment.

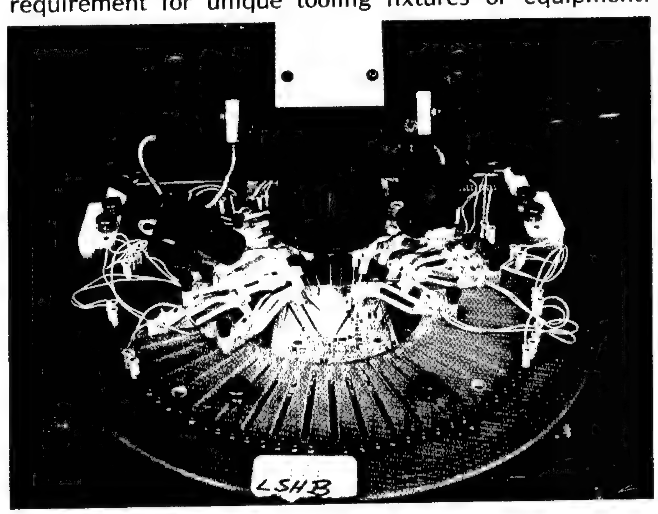


Figure 5

Fixtures that were fabricated were based on the circuit under test and were independent of the LSH technology being evaluated. For example, the assembly burn-in sockets and biasing boards would have been the same for the spin and precession board implemented with either the normal PCB approach or the LSH Technology since form, fit, and function were maintained.

Pilot Production

Figures 6 and 7 show the processing steps necessary to fabricate the LSH assemblies. In each case, processes were common to standard hybrid manufacturing technology but had minor changes to accommodate the larger substrate.

The LSH technology lends itself to improvements through quality control procedures since yields may be monitored and corrective action taken at several points in the fabrication and assembly process. As shown in the process specifications, samples are taken for analysis at steps throughout the process.

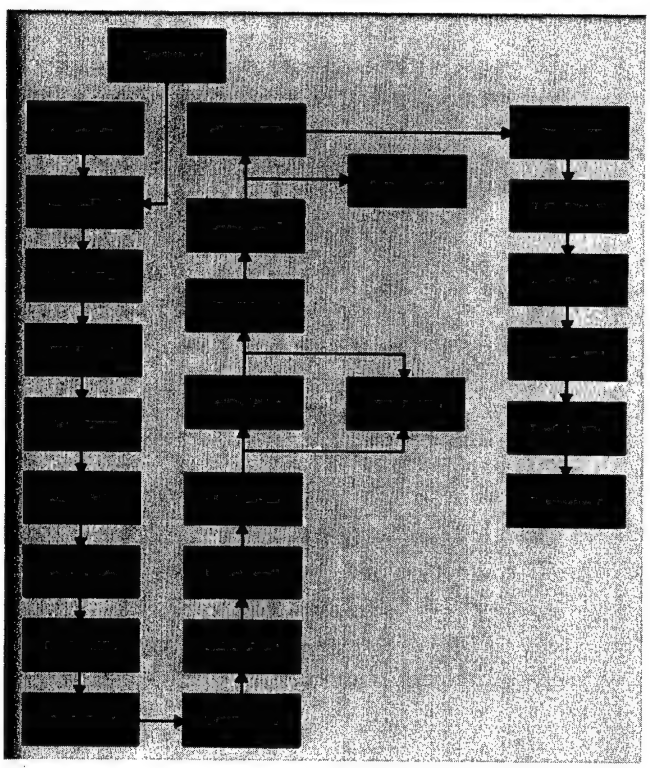


Figure 6

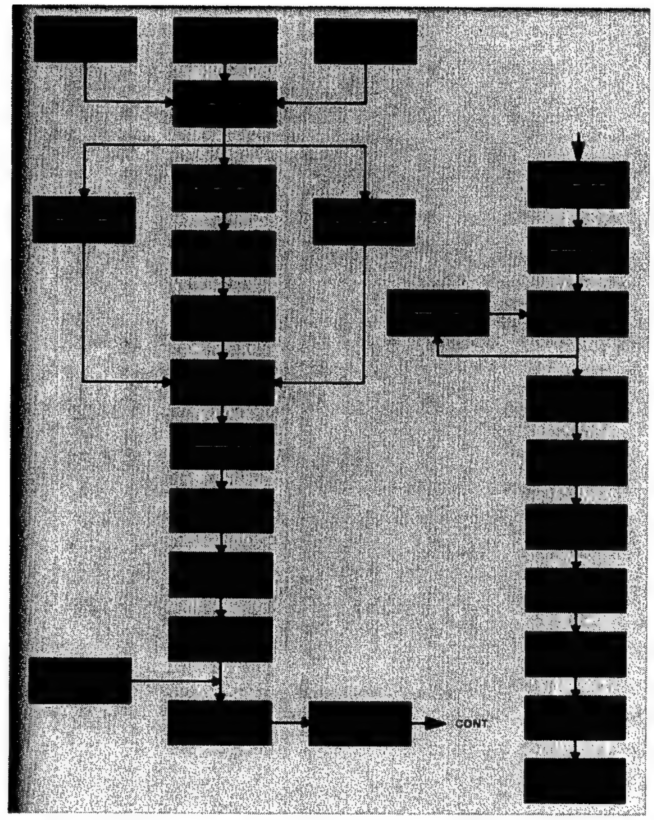


Figure 7

All parts and materials receive inspection in accordance with purchase specifications upon arrival at the Microelectronics Center. Particular parameters are of importance to the LSH technology. Substrates must meet more rigid requirements for surface finish, ripple, and camber to allow both good line definition and consistent thick film thickness. Active chips should be sampled for both dc and ac parameters by packaging in the intended hermetic chip carrier and subjecting to electrical testing at ambient, low, and high temperatures. Acceptance testing of HCC packages and lids is also important to assure plating integrity, seal ring flatness, and soldering properties. HCCs are qualified by subjecting a sample to solderability, high temperature bake, seal, and moisture resistance with conditions and test methods similar to those used on hybrid packages. Chip components (e.g., ceramic capacitors) should be tested also for solder

leaching and wetting since consistency during reflow solder assembly is critical.

Normal processing controls during thick film printing were intensified with regard to consistency of print over the larger than normal area. Adjustments such as leveling of the bed and squeegee pressure and speed were more critical than on small substrates. Visual inspection plus a light section microscope were used to check sample substrates. When printing resistors, three samples were run with each paste value dried, fired, and measured prior to committing the balance of the lot to firing. Any abnormalities would result in cleaning the unfired resistors off, corrective action, and reprinting using another set of samples. Although completed large scale substrate assemblies may have a high dollar value, use of additional substrate samples during the thick film operation is inexpensive when considering the marginal cost of materials.

Overriding factors in achieving a cost effective total LSH process are the quality and reliability of the active devices used. Quality is reflected in the yield of the HCCs up to the point of reflow attachment whereas reliability addresses the ability to perform as required by the circuit at final test following assembly screening. Quality was controlled by lot acceptance testing of incoming chips and packages plus assembly process controls for eutectic and epoxy die attach. Preseal screening through the use of 100 percent nondestructive wire bond pull testing provided both yield assurance at the HCC level and a safety margin for the wire bonds to withstand high shock loading in the final assembly. Sealing was checked through first piece hermeticity testing prior to each package seal lot for both the furnace sealed parts and the seam sealed parts.

HCC screening for improved reliability did not include powered burn-in on devices in this contract due to fixturing cost and socket availability. However, higher volumes would justify such expenditure since three assembly failures were attributed to active devices.

Process controls are of increased importance at this point due to the expense and limitations on total assembly rework. Solder paste screening required initial and periodic measurement for deposited thickness plus 100 percent visual inspection for screen clogging, alignment, or improper lift off. Setup utilized sample substrates and nonfunctional HCCs plus chip capacitors to verify the settings on the printer, drying time, and three zone belt reflow machine. One hundred percent inspection of part placement was necessary to assure proper orientation and alignment prior to reflow. Errors detected prior to paste drying could be corrected by repositioning with some risk of resultant inadequate solder at some joints. A more repeatable process was to remove all parts from the substrate, clean all constituents, and then repeat the controlled solder printing and chip placement.

Connector pins clipped over Pt-Au pads and hand soldered resulted in some yield loss due to the manual operations of forming, placement, and soldering. Although acceptable yields were obtained through the use of skilled operators, higher volume production would require a more consistent method such as the use of solder paste and/or pre-tinned pins with a controlled heat source to provide reflow soldering.

Cost Analysis

The main cost advantage of the LSH technology is visibility and cost control capability which is characteristic of processes with adjustable yields. Tradeoffs may be performed from the point of material selection through final assembly screening to improve yields at various processing steps by means of inspection and testing.

Due to the sensitivity of cost information on the Navy GP circuits, the cost comparison is based on normalizing all dollar amounts to the total Navy GP board cost for a lot size of 200 assemblies. The table below gives the cost comparison.

	PWB Assembly	LSH Assembly
Material	51.9	17.9
Assembly and Test	23.7	28.9
Support	8.1	11.9
Quality	16.3	5.5
Total Cost	100.0	64.3

The major contributor to the cost differential of 35.7 percent is the cost of active devices which are purchased as packaged, fully tested devices for the PWB assembly as opposed to partially tested chips and packages for the assembly.

Cost projections based on experienced learning factors and nonrecurring costs and normalized to 100 percent for an LSH assembly lot size of 200 are as follows:

Lot Size	Cost Percentage
200	100.0
1,000	78.4
10,000	60.0
100,000	46.6

Reliability Analysis

Environmental testing was used to accelerate failure mechanisms which could produce reliability risks in the LSH assembly. The first series of tests were done on 1 inch x 1 inch substrates and materials typical of those used in the LSH assembly. The primary concern was the ability to withstand temperature stresses and moisture. The second series of tests were done on full sized LSH substrates with single layer metallization connecting HCCs in a continuity test pattern. Chip capacitors were also reflow soldered onto these test assemblies. Backplate material was applied to 50 percent of the samples. These LSH test assemblies were step stress tested for mechanical shock, vibration, constant acceleration, temperature cycling, and thermal shock to determine safe design limits.

Analysis of the backplate strength indicated that further increases in environmental capacity could be achieved by trading weight for increased backplate thickness. Temperature cycling capability was dependent on selection of materials having compatible thermal coefficients of expansion rather than the robustness of individual solder joints. Testing of several conformal coatings indicated some necessity to provide protection to ceramic chip capacitors where high humidity is characteristic of the application environment. These techniques were found to be appropriate for systems in the early design phase where normal hybrid techniques would be considered an alternative to printed circuit board construction or the use of custom LSI.

Manufacturing Considerations

Based upon these tests and work conducted on this project, several important considerations were found for the manufacturer of large scale hybrids using hermetic chip carriers.

1. LSH processing is practical using equipment which is standard within the hybrid industry. Yields of 90.3 percent for assembly and 82.2 percent for screening were attained.

2. Material compatibility over the full range of the intended application should be verified prior to commencing production.

3. Process controls should be established to detect defects early in the production process.

4. Process yields are controllable through choice of inspection and test points. Tradeoffs of process control costs versus improved yields at subsequent steps should be made.

5. Environmental capability of the large scale hybrid ceramic substrate may be extended through the use of a compatible backplate material such as graphite-epoxy. Missile launch environmental capability is attainable.

6. Density may be increased by use of multilayer thick film networks and placing of hermetic chip carriers on dielectric.

7. Conformal coating is necessary if the application environment includes moisture exposure such as that characterized by the standard moisture resistance test.

8. A mechanical strength increase of 50 percent in the Y1 axis is achievable by use of a 0.125 inch thick backplate which would be compatible with the Navy GP mounting requirements.

To improve the general applicability of this technology, the following areas for investigation are recommended:

1. Determination of a conformal coating which provides adequate protection to passive devices on open large scale hybrids applied in a high moisture environment.

2. Determination of thermal management considerations for large scale hybrids which incorporate high density techniques and compatible backplates.

Brief Status Reports

Project 3253. High Current Density Cathodes. Thermionic cathodes have heating and cooling problems. High operating temperatures reduce the lifetime of the cathode. This project is to establish the manufacturing processes for thin film field emission cathodes, which do not require heater power and cooling equipment. Sperry Univac etched holes through resist to the surface of the silicon wafer. Holes were then metallized to form emitter spikes. Planar plasma etching may permit hole spacing to be reduced from 12 to 4 microns, increasing current density. For additional information, contact W. Patterson, MICOM, (205) 876-2710.

Project 3254. Semi-Flexible Thin Film Semiconductors (CAM). Present circuit boards lack the packing density and stringent packaging qualities projected for future missile electronic systems. The project purpose is to develop a manufacturing process for putting thin film microcircuits on flexible substrates. Micro-Electronics Corporation is fabricating functional thin film circuits using the pilot line from Phase 1 work. New materials, coatings, and high gain transistor configurations are under test and evaluation. Yields were improved. For additional information, contact R. Brown, MICOM, (205) 876-5742.

Project 3263. Printed Wire Boards Utilizing Leadless Components. The volume, weight, quantity, reliability, and cost of Printed Wire Boards using axial leaded components can be substantially improved. The purpose of this project is to use leadless components currently available to reduce the required area by a ratio of 2 to 1 with a corresponding weight reduction. Reliability may be increased due to a reduction in the number of plated through holes required for interconnections. MicroElectronics Engineering will establish production processes for soldering leadless microelectronic components to flexible boards and for applying conformal coating. Belt reflow soldering and vapor phase solder reflow will be evaluated. For additional information, contact V. Ruwe, MICOM (205) 876-8650.

Project 3372. Manufacturing Methods for Magnetic Materials. New magnetic devices present many manufacturing problems from application of the insulation system to displacement of winding locations and tension. This project is to establish and test fabrication techniques for small encapsulated transformers; also, to implement and evaluate low cost techniques for manufacture of subminiature electromagnetic devices. The three methods of encapsulating transformers—transfer molding, injection molding, and liquid injection molding—have been investigated. Liquid injection molding seems most promising due to the pressure involved. A conducting sphere is being used to reduce voltage gradients while joining. Molding equipment is being procured to demonstrate continuous potting and encapsulation. For additional information, contact R. Kotler, MICOM, (205) 876-2065.

Project 3376. Testing Electro-Optical Components and Subsystems. Manufacturing technology necessary for production of electro-optical systems is very limited; little correlation exists between component specifications and the parameters that impact system performance. Economy of production, testing methods, or techniques could be developed by validating existing specifications or replacing existing ones with specifications that are based on system performance rather than component performance. Preliminary analysis indicated that the throughput limitations and phase measurement complications might be improved by combining the technology used for processing radar signal data with linear scanning. This would provide rapid characterization of defects. For additional information, contact W. Friday, MICOM (205) 876-3376.

Project 1024. MMT of Radio Frequency Stripline Hybrid Components. The trend in stripline technology is to integrate within the stripline element both active and passive discrete components. Two problems need resolution: (1) the need for extreme dimensional accuracy and (2) compensation variable dielectric thickness. This project is to develop a program to establish requirements, processes, quality assurance, and limitations of placement, assembly, and interconnection for incorporating discrete components integral with RF stripline components. Hughes will adapt semiadditive circuit board processes to stripline and microstrip hybrids. Transmission media for millimeter wave signal control devices were analyzed and development of frequency multiplier diodes has begun. For

additional information, contact L. Woodham, MICOM, (205) 876-7734.

Project 3133. Lithium Ferrite Phase Shifter for Phased Array Radar. The garnet presently used in phased arrays is costly, and the manufacturing process is difficult and expensive. This solution will be to make use of lithium ferrite. The process will allow the lithium ferrite to be co-fired in place around the dielectric. Raytheon designed and made tooling for production of the co-fired ferrite and dielectric inserts. They used carbide mandrels and outer bags to form green toroid rods. They have nearly completed work on isostatic pressing and firing of lithium ferrite phase shifters. The effort improved yield, magnetic properties, and dimensional tolerances. Test results have been very encouraging. For additional information, contact P. Ormsby, MICOM, (205) 876-4933.

Project 3146. Process Development of Photolithographic Process. Screen printing of fine lines does not allow high density due to rheology of ink systems. The project plan is to establish technology for etching thick film materials for multilayer circuits. MicroElectronics Corporation made screens for fabricating high density multilayer hybrid circuits with 3 mil lines and 3 mil spaces. The goal is to use optimum materials, single firing, and improved photolithographic techniques to increase yield and reduce cost. For additional information, contact G. Little, MICOM (205) 876-3848.

Project 3147. Additive Processes for Fabrication of Printed Circuit Boards. The subtractive process of making printed circuits is a large user of copper, and the waste material is difficult to dispose of. The project purpose is to fully develop the additive process to meet military requirements; this will reduce the cost of printed circuits and conserve copper. Hughes is using an automated electroless copper plating process to chemically deposit copper conductor patterns. The goal is to achieve patterns with circuit bonds equivalent to those produced by high temperatures and high pressure laminations. For additional information, contact R. Brown, MICOM, (205) 876-5742.

Project 3160. Cleanliness Criteria & Processes for Printed Wiring Boards. Criteria for printed wiring board cleanliness is vague and costs associated with it are a high percentage of final product cost. This project is to develop process techniques for various levels of cleanliness and eliminate non-cost-effective operations. Martin Marietta is establishing a process to identify, quantify, and remove contaminants remaining on PCBs after normal cleaning. Liquid phase chromatography is being used. For additional information, contact R. Brown, MICOM, (205) 876-5742.

Project 3381. Low Cost Improved 2-D Heatshield Manufacture. Heatshield fabrication by tape wrapping is a low speed, high cost process. The purpose of the project is to develop splice free heat shields using the braiding process. Because of high cost, braiding of commercial silica yarn was dropped. A series of various construction flat E-glass braids were successfully made for leaching trials and prepregging evaluation. As a result, a braid design and process flow were selected. For additional information, contact B. Park, MICOM, (205) 876-4057.

Project 3743. Composite Spun Material Launching Beam for Bridges. Related to providing a light weight traversing beam with low flexibility, this project purpose is to spin the beam by using high strength, high modulus graphite fibers in an epoxy matrix with integral connectors. Production line equipment was installed, die molds were fabricated, a winding machine was fabricated and installed, and raw material was procured. Trial runs of individual components are finished. The upper and lower chord windings have been completed; the second winding was accomplished with a revised procedure and resin system, which was successful. For additional information, contact R. Helmke, MERADCOM, (703) 664-5594.

Project 3749. Hydraulic Rotor Actuators. Rotary actuator models have never been produced on a quantity basis. The project purpose is to reduce difficulties that are anticipated in obtaining the required close tolerances and microfinishes with standard production tools. Draft specifications, assembly procedures, and manufacturing routing sheets were submitted. On-vehicle testing was completed and actuators shipped to Bird-Johnson Company. Leakage and wear analysis was started. For additional information, contact

R. Nette, MERADCOM, (703) 664-5384.

Project 1021. Computerized Production Process Plan for Machined Cylindrical Parts (CAM). Present manual methods for production process planning of machined cylindrical metal components are inadequate due to high process planning costs and a lack of standardization. The purpose of the project is to develop a computer software system for process planning of machined cylindrical parts. The system will be manufacturer independent and will incorporate process decision modeling. The parts were programmed and tested. The administrative capabilities were added to the software that builds and uses the data base files. The readability of data base documentation was improved. Work is continuing on reference service selection, dimensioning, and the tolerance data base. For additional information, contact R. Kotler, MICOM (205) 876-2065.

Project 1026. Production of Low Cost Missile Vanes. Metal control vanes, fins, and missile fairings cause high cost weight penalties and long lead times. Automation of composite materials offers an opportunity to meet low cost and weight criteria for production. The effort provides for automation of preengineered broadgoods on an N/C tape laying machine. The major objectives of this effort are to automatically cut, assemble, and transport materials to fabrication work stations. All tool design activity was completed. The process development for bonding the honeycomb to the torque box has been completed. A three-dimensional finite element model was developed and analyzed using Nastran. For additional information, contact E. Croomes, MICOM, (205) 876-1740.

Project 3268. Automatic Control of Plating (CAM). The baths used for plating printed wiring boards have an extremely large number of variables which influence PCB quality. If any variable drifts out by relatively narrow bounds, impaired quality results. The project purpose is to develop a centralized controller system which will sense multiple inputs, keeping process parameters in balance. The control software is operational. Software has functioned in test runs simulating the control of nine plating tanks. Modifications to the automatic plating line are nearly complete, and the control equipment has been positioned. The assembly and installation of the automatic monitoring and control system on a General Dynamics plating line is completed. For additional information, contact L. Woodham, MICOM, (205) 876-7734.

Project 2194. Production Processes for Rotary Roll Forming. Mechanically joining or welding a conventional closure to commercial tubing is expensive. The purpose of the project is to develop methods for producing integral nozzles with tubular products using rotary roll forming techniques. Battelle's Columbus Laboratories has established the manufacturing techniques and procedures for roll forming nozzle contours in line pipe, evaluation of prototype components, and tolerance optimization. For additional information, contact W. Crownover, MICOM (205) 876-3294.

Project 3169. Optical Inspection of Printed Circuit Boards. Operator fatigue allows many bad PC Boards to pass visual inspection. This project is to provide an automated optical comparator to eliminate the need for a human inspector. An operating inspection system was designed, assembled, and used to establish operating parameters, capability, and cost effectivity on a high speed production line. A production prototype has been manufactured. For additional information, contact R. Brown, MICOM, (205) 876-5742.

Project 3217. Automated Production Methods for Traveling Wave Tubes. The SAM-D traveling wave tube is the most expensive component of a guidance system and is a significant system cost driver. A fundamental change of concept in the manufacturing process is required. The project purpose is to develop automated procedures to perform fabrication processing and test operation that presently requires extensive labor. Litton built and tested eight traveling wave tubes. Several were accepted. A pilot line will be run to build 20 tubes from 26 or fewer starts; tubes must pass 300 fast start test and 300 hour life test. Some tubes were made with lower cost parts, saving $600 per tube. For additional information, contact V. Irelan, MICOM, (205) 876-4473.

Project 3165. Production Techniques for Sealing Hybrids. About 20% of the hybrid rejection rate is

associated with sealing. This project is to investigate equipment, methods, and materials to determine optimum combinations to increase yields. At MICOM a hybrid circuit hermetic sealer and leak test system is under construction. M & K Association installed the fine leak test chamber. Solid State Engineering Corporation assembled the custom dry box system. The hybrid package was parallel seam welded and leak tested in dry nitrogen. For additional information, contact V. Ruwe, MICOM, (205) 876-8650.

Project 9838. Miniature Cathode Ray Tubes. The present miniature Cathode Ray Tubes are too expensive and do not have image quality to allow for mission requirements. There are no sources for the required tubes in desired quantities. This project is to establish a source and manufacturing process toward better control and simpler procedures to eliminate production variables and hand manufacturing steps. Thomas Electronics fabricated the tube utilizing the new gun structure and deflection coil. The deflection coil was redesigned to increase sensitivity. Modifications to the electronics were made to reduce the spot size. For additional information, contact C. Deane, ECOM, (703) 664-1541.

Project 9813. Ruggedized Low Cost Quadrant Detector for CLGP. Silicon quadrant detector for optical fuzes are too costly because assembly of the silicon detector to the lens and case is performed by hand. The project is to develop methods for applying the lens to the silicon detector and the detector to the case. Deep etching will be used to reduce stress risers formerly caused by surface grinding. Texas Instruments established processes for fabrication of ruggedized silicon quadrant detectors for use in CLGP. Processes include epoxy bonding silicon detectors and packaging. For additional information, contact M. Skeldon, ECOM, (703) 664-4287.

Project 3031. 10.6 Micron CO_2 Lasers. Lasers constructed in unit quantities are expensive and vary in specifications. Present range finder lasers have reduced all weather capabilities and are ineffective against countermeasure smokes. This project was to establish large scale production of laser components including mirrors, electrodes, and laser envelopes to reduce costs and develop units that are resistant to the shock and vibration of a tank environment. Raytheon is developing CO_2 laser production methods to insure alignment integrity in adverse environments. Critical areas being optimized include mirror alignment, electrode contouring, and gas mixture. The production of initital samples is under way. For additional information, contact C. Fox, ECOM, (703) 664-4931.

Project 9857. Auto Separation, carrier Mounting & Testing of Semi-CDT Dice. The separation of small dice from the wafer is now done by hand. The die must be handled individually during attachment to the package and wired to terminals by working through a microscope. The project is to develop a means for separation of die and for placing them on a carrier suitable for test, burn-in, and attachment to the package. There is also a need to write automatic test programs. Honeywell and ERADCOM rescoped the project to run 1200 counter circuits. Each hybrid contains two counter chips, one shift register chip and a capacitor. Tape automated bonding was used on all chips. About 1200 counter hybrids have been built using tab. Honeywell completed a pilot assembly line for a counter hybrid and sent 1200 units to ERADCOM. The line used tape-carrier mounting of chips for burn-in, testing, and placing in circuitry. Over 93% of tested tab chips were good. For additional information, contact I. Pratt, ERADCOM, (201) 544-2308.

Project 9845. Computer Aided FLIR Aspheric Lens Fabrication. Aspheric lenses required by FLIR sensors have severe weight and size limitations and are difficult to manufacture because of the repetitive process of surface shaping. The purpose of the project is to provide manufacturing methods for producing aspherical FLIR lenses using a single point diamond turning lathe integrated with computer controls and laser intefermetric feedback of cutting tool position. Honeywell made several flat germanium blanks by compaction, casting, and diamond turning. They made vacuum chucks to hold half finished lenses during aspheric turning. At this time four aspheric aluminum mirrors and sixteen aspheric germanium lenses have been fabricated via diamond turning. For additional information, contact J. Adamson, ECOM, (703) 664-6666.

Project 5002. Fabricating Torsion Bar Springs From High Strength Steels. Engineering alloy steels can be heat treated to a maximum working hardness which requires large diameter bars, thereby interfering with design fits and increasing weight. This project will establish methods of fabricating torsion bars utilizing 300,000 minimum yield materials. Drawings of test parts were completed and released for procurement. Test specimen steel was partly received. Remaining test specimens will be made when all materials are on hand. For additional information, contact M. King, TACOM, (313) 574-1814.

Project 5014. Improved Foundry Castings Utilizing CAM. Foundry casting processes are wasteful of raw materials and energy. This project will optimize casting processes by digital computer analysis of advanced fluid flow and thermal activity. Work on the fluid flow simulation has begun. Instrumentation for the casting tests has been debugged and tests are in progress. The heat flow analysis is showing good agreement with experimental results. Molds were being designed utilizing the computer program, and simulation results are in good standing with test results for simple shaped castings. For additional information, contact W. Wassel, TACOM, (313) 574-5814.

Project 5019. Tactical Vehicle Storage Battery. The major cause of tactical vehicle battery failure is battery container breakage. This project will provide a new high impact plastic container to increase field performance requirements and to accommodate the maintenance free concept already released in larger military battery sizes. At this time, the battery requirements and basic design of storage battery has been established. For additional information, contact J. Reinhan, TACOM, (574) 313-6492.

Project 4575. Laser Welding Techniques for Military Vehicles. There is no manufacturing baseline existing for welding high strength material by advanced high speed welding techniques. This project will study the use of laser welding and establish a production baseline. A liaison is established with Chrysler to ensure coordination with the XM-1 program. The process has been refined so repeatable sound welds can be made. Process optimization is underway to eliminate porosity in the weld. An automation concept study is being performed and equipment to weld section mock-ups is being prepared. For additional information, contact D. Pyrce, TACOM, (313) 574-5814.

Project 4586. Improved Large Armor Steel Castings. Present casting techniques need updating in order to exploit the advantage of the casting process. The project will establish in production techniques for controlling soldification rates in molds to improve properties and reduce costs. Dual contracts were awarded to Rockwell and Blaw-Knox. Flat plates from both contractors have been evaluated ballistically and found to exceed the acceptance requirements for rolled homogeneous armor. For additional information, contact D. Phelps, TACOM, (313) 574-5444.

Project 3438. Delidding, Parallel Seam Sealed Hybrid Microelectronic Packages. There are no production techniques or equipments available to accomplish the delidding of hybrid packages. The project purpose will develop a delidding device utilizing a permanent diamond lap to its maximum advantage. Westinghouse is working jointly with the Navy on this project. Westinghouse established improved techniques for delidding and resealing hybrid packages. Both welded planar and soldered packages were successfully resealed by welding. For additional information, contact P. Wanko, MICOM, (205) 876-7097.

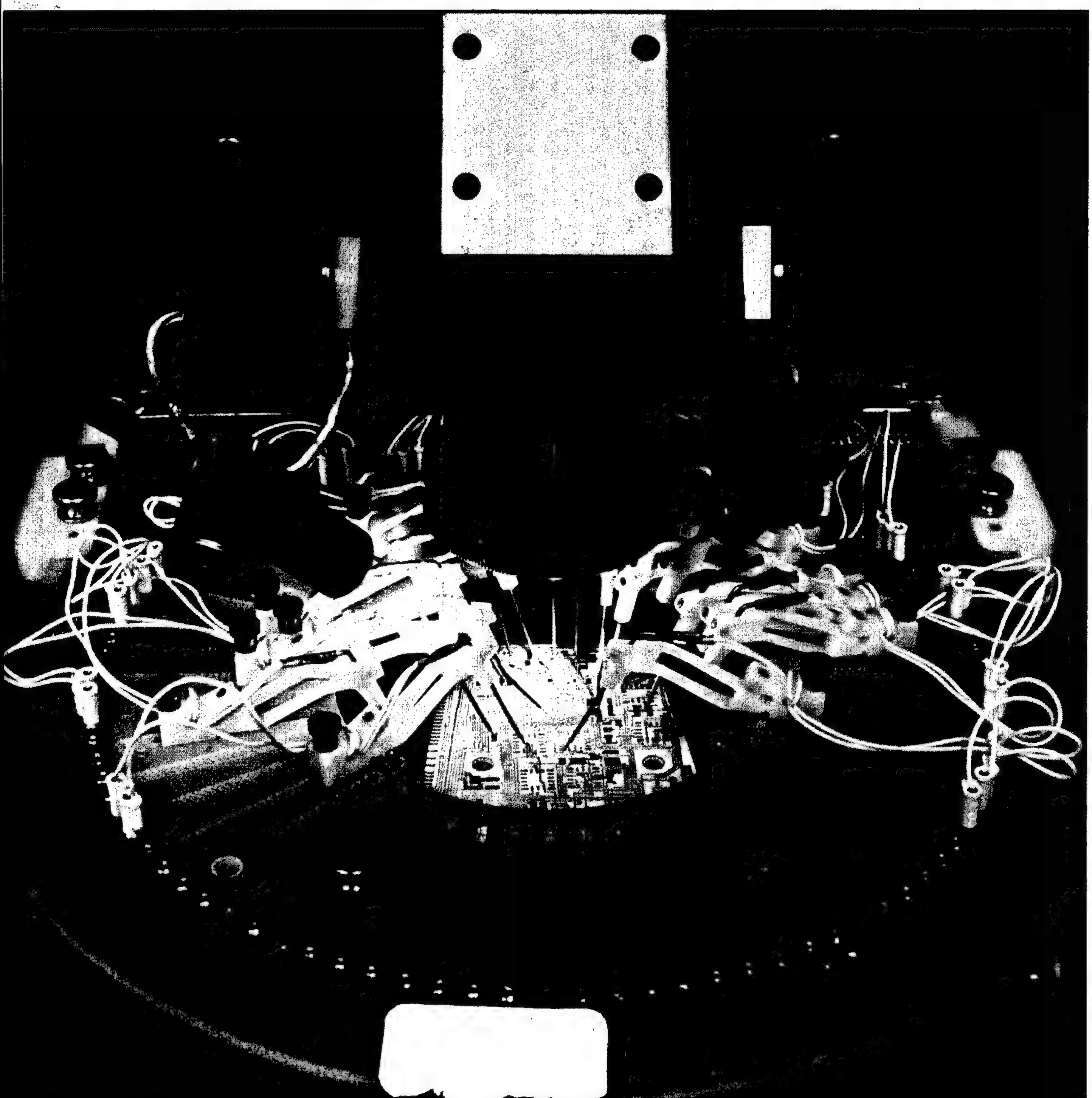
Project 3435. Simplification of High-Power Thick Film Hybrids. The present method of cooling high power hybrid circuits involves a complex and expensive procedure used only on limited production items. The use of a single beryllia substrate has been demonstrated but needs further development. A manufacturing process will be developed to screen and fire thick film inks onto beryllia surfaces. Commercial inks will be evaluated for compatibility with beryllia and the toxicity of beryllia will be taken into account. Westinghouse is establishing methods to screen and fire conductor, resistor, and dielectric pastes onto beryllia substrates. Laser trim system capable of safely handling beryllia vapor will be used. The modification of existing equipment was determined. For additional information, contact L. Woodham, MICOM, (205) 876-7734.

US Army

ManTech Journal

Making Things Better

Volume 7/Number 2/1982



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Contents

1 Comments by the Editor

3 NLAB's Mission: Soldier Survival

10 Armaments Testing Data Computerized

18 Opacity/Particulates in Forge Exhaust

24 Cannon Chambers Profiled Faster

28 Auto Assembly of Hybrid IC's Achieved

31 New Technique Measures Oscillator Sensitivity

37 Five Task Program Sets New Tone

41 Brief Status Reports

Inside Back Cover — Upcoming Events

ABOUT THE COVER:

Automated laser trimming of substrate networks for large scale hybrid microcircuits is seen here in process at Martin Marietta. Used on a manufacturing technology project for the U. S. Army Missile Command, the technique facilitates efficient fabrication of a ceramic alternative to printed circuit boards. Trimming of each unique resistor network is controlled by a computer program which indexes the laser source and receives dynamic feedback through the needle probes. This method has achieved accuracies better than 1%, substantial savings in labor and throughput, and 100% acceptable substrates. For further information, contact Mr. Lee Mirth, (305)352-5557. (Photo courtesy of Martin Marietta Corporation.)

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Comments by the Editor


RAYMOND L. FARROW

It was six years ago this month that initial plans for reporting the results of the Army's part in the tri-service/industry manufacturing technology program took shape in the form of a quarterly journal. This magazine was the result of these plans, and since that time, twenty-four issues have reported on Army mantech projects and also on the activities of the Manufacturing Technology Advisory Group. Included also have been reports on several projects of the U.S. Navy and Air Force.

The importance to the nation of this mantech effort has been clearly reflected by the marked increase in funding the current administration has provided for expanded manufacturing technology research and development through the next five years. This dramatic mantech expansion will form the basis for a much more responsivle, effective industrial base upon which the nation can call in the event of an international emergency.

Our next two issues of the Army ManTech Journal will feature guest editorials from the Department of Defense Office of the Under Secretary of Defense for Research and Engineering. We think our readers will find these editorials to contain some significant information pertaining to our national industrial base goals.

This issue of the Journal features an article outlining some of the outstanding work accomplished at the U.S. Army Natick Laboratories. NLAB's five operational segments provide full support to the individual soldier's personal needs and equipments and his survivability under any environmental or military condition. There will be another article in a coming issue further describing NLAB's considerable activities and responsibilities.

An article on page 10 about the computerized processing of test data for various armament items at the U.S. Army Armament R&D Command points up the vast savings in time now possible (since the replacement of older manual methods of data reduction.)

Another ARRADCOM project is the subject of an article on page 18 describing the use of optical measurements of exhaust emissions to determine accurate particle concentrations. The new technique is applicable to many forge shop operations.

Fast, accurate measurement of cannon chamber profiles is the subject of an article on page 24 describing development at Watervliet Arsenal of a measurement system utilizing electronic and optical scanners in a mechanical assembly driving a digital display and printer to record total part configuration. This development by the U.S. Army Armament Materiel Readiness Command advanced inspection capabilities markedly.

The U.S. Army Missile Command mantech program on fabrication of electromagnetic components is highlighted in an article describing that five task effort. An extremely interesting facet of this two year project was the rapid dissemination of new information to industry while the program was under way. Thus, this critical industry

could implement the results of the program immediately rather than having to await a final report following completion of the project. This technology transfer procedure could be an important lead to follow as our national mantech effort gains speed.

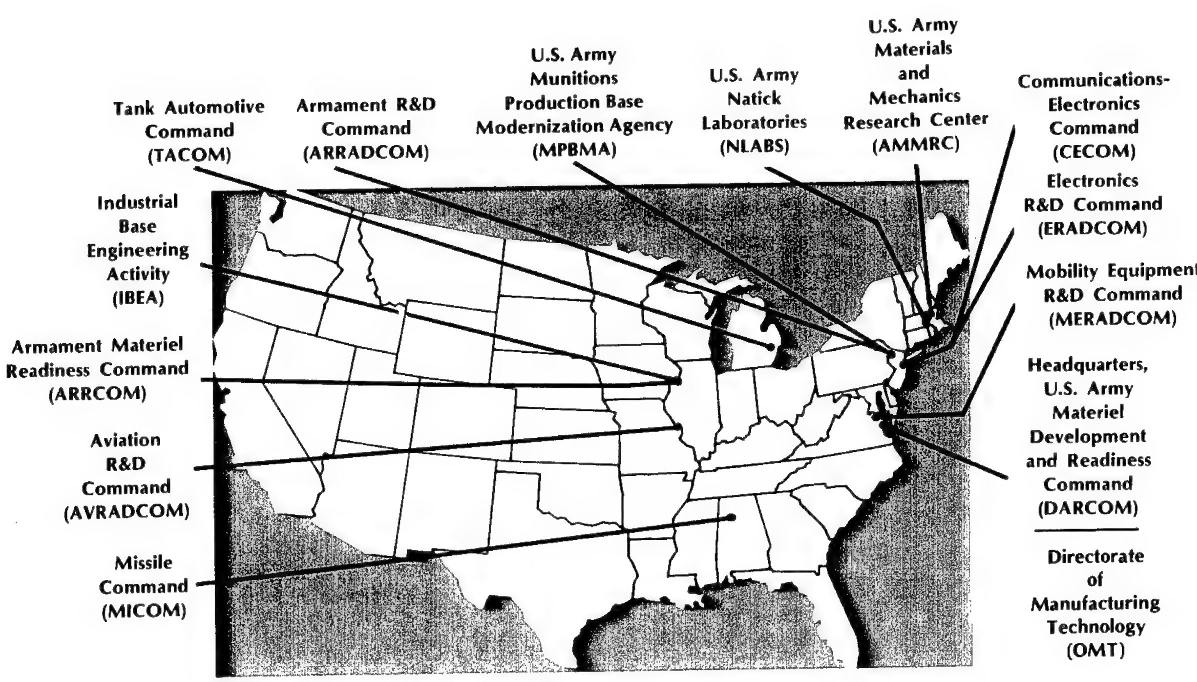
The automated assembly of hybrid integrated circuits is described in an article on the Communications Research and Development Command's project that now makes mass production of these components practical. This development will have a profound impact on Army and DoD systems through greater availability of these electronic items.

Fuzes now can be tested during production with a new technique measuring oscillator sensitivity that was developed in-house at Harry Diamond Laboratories for the Electronics Command. Small anechoic chambers are employed.

Again, we feature a large number of brief reports of ongoing Army mantech projects which serve to keep our readers up to date on current Army manufacturing activities.

I would like to remind all readers that your comments on this journal are appreciated, so that we may better serve the information needs of the manufacturing technology community.

DARCOM Manufacturing Methods and Technology Community



"We're Making Things Better!"

NLABS' Mission: Soldier Survival

By

Frank Civilikas
Project Engineer
U. S. Army Natick Laboratories

The U.S. Army Natick Research and Development Laboratories (NLABS) is located 15 miles southwest of Boston, with its campus situated on a peninsula which projects out into Lake Cochituate. Its primary mission is to sustain an effective military person under all conditions: what one eats, carries, wears, sleeps in, and protects himself with. Its work has saved a countless number of lives and many millions of dollars.

During World War II, the missions now housed at Natick were scattered throughout many states under the command of the Army Quartermaster Corps. Chemical, plastic, and textile work was located in Philadelphia; food and container work was located in Chicago; mechanical and other items were in Indiana; and environmental studies were in Massachusetts. It was thought that when scientists, technologists, and engineers were brought together in a pleasantly situated and well designed and equipped set of laboratories, they would be motivated to act as a team, and in doing so develop an institutional pride that stimulates productivity. Gradually, they were brought together in their present location, forming Natick Labs.

Its staff includes several noted experts in such areas as anthropology, stress physiology, chemistry, biochemistry, and entomology.

Four Commodity Tasks

NLABS is concerned with the basics of military life—specifically, food, clothing, shelter, and associated products (Figure 1). Its laboratories are organized into five separate operational areas: Food Engineering Laboratory, Science and Advanced Technology Laboratory, Individual Protection Laboratory, Aero-Mechanical Engineering Laboratory, and Operations Research Systems Analysis.

The **Food Engineering Laboratory** provides scientific and engineering efforts to develop feeding systems, including rations, ration components, packaging, and food service equipment (Figures 2 and 3). In addition, it provides procurement instruments, engineering support, and operational assistance to DSA, DoD, and other Government agencies such as NASA, GSA, and USDA.

Working closely with the Food Engineering Laboratory, the **Science and Advanced Technology Laboratory** directs basic and applied research and development in support of improved feeding systems, prevention of microbiological deterioration of material, and pollution abatement. The pollution abatement work deals with wastes from munition plants and the disposal of used military supplies. Physical, chemical, and biological techniques are studied to minimize pollution.

Conducting the Army's research and development program on uniforms, protective clothing, personnel armor, and life support equipment systems, the **Individual Protection Laboratory** is the source of technical information used to develop specifications for military procurement purposes. It provides engineering support to procurement agencies in the Department of Defense, GSA, and U. S. Postal Service.

NOTE: These manufacturing technology projects that have been conducted by the U.S. Army Natick Laboratories were funded by U.S. Army, U.S. Navy, and U.S. Air Force agencies under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The NLABs Point of Contact for more information is Mr. Frank Civilikas, (617) 633-4883.

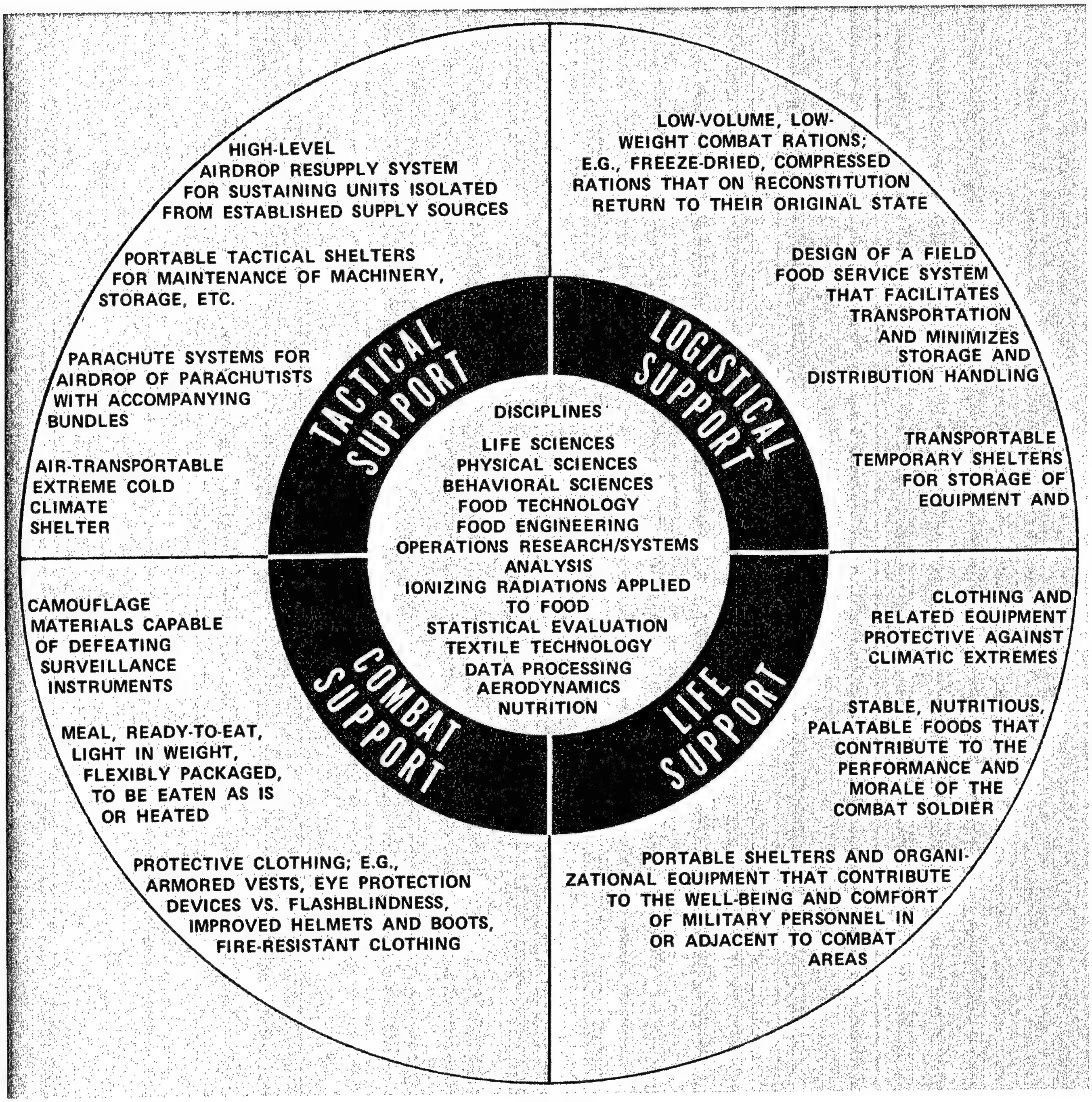

HIGH-LEVEL AIRDROP RESUPPLY SYSTEM FOR SUSTAINING UNITS ISOLATED FROM ESTABLISHED SUPPLY SOURCES
PORTABLE TACTICAL SHELTERS FOR MAINTENANCE OF MACHINERY, STORAGE, ETC.
PARACHUTE SYSTEMS FOR AIRDROP OF PARACHUTISTS WITH ACCOMPANYING BUNDLES
AIR-TRANSPORTABLE EXTREME COLD CLIMATE SHELTER
LOW-VOLUME, LOW-WEIGHT COMBAT RATIONS; E.G., FREEZE-DRIED, COMPRESSED RATIONS THAT ON RECONSTITUTION RETURN TO THEIR ORIGINAL STATE
DESIGN OF A FIELD FOOD SERVICE SYSTEM THAT FACILITATES TRANSPORTATION AND MINIMIZES STORAGE AND DISTRIBUTION HANDLING
TRANSPORTABLE TEMPORARY SHELTERS FOR STORAGE OF EQUIPMENT AND
TACTICAL SUPPORT
LOGISTICAL SUPPORT
COMBAT SUPPORT
LIFE SUPPORT
DISCIPLINES
LIFE SCIENCES
PHYSICAL SCIENCES
BEHAVIORAL SCIENCES
FOOD TECHNOLOGY
FOOD ENGINEERING
OPERATIONS RESEARCH/SYSTEMS ANALYSIS
IONIZING RADIATIONS APPLIED TO FOOD
STATISTICAL EVALUATION
TEXTILE TECHNOLOGY
DATA PROCESSING
AERODYNAMICS
NUTRITION
CAMOUFLAGE MATERIALS CAPABLE OF DEFEATING SURVEILLANCE INSTRUMENTS
MEAL, READY-TO-EAT, LIGHT IN WEIGHT, FLEXIBLY PACKAGED, TO BE EATEN AS IS OR HEATED
PROTECTIVE CLOTHING; E.G., ARMORED VESTS, EYE PROTECTION DEVICES VS. FLASHBLINDNESS, IMPROVED HELMETS AND BOOTS, FIRE-RESISTANT CLOTHING
CLOTHING AND RELATED EQUIPMENT PROTECTIVE AGAINST CLIMATIC EXTREMES
STABLE, NUTRITIOUS, PALATABLE FOODS THAT CONTRIBUTE TO THE PERFORMANCE AND MORALE OF THE COMBAT SOLDIER
PORTABLE SHELTERS AND ORGANIZATIONAL EQUIPMENT THAT CONTRIBUTE TO THE WELL-BEING AND COMFORT OF MILITARY PERSONNEL IN OR ADJACENT TO COMBAT AREAS

Figure 1

Figure 2

Figure 3

The **Aero-Mechanical Engineering Laboratory** develops new systems, equipment, and techniques for the airdrop of personnel, supplies, weapons, and heavy equipment from aircraft in flight; for field shelters to protect personnel and equipment from worldwide environmental conditions; and for organizational equipment to support the soldier in the field. This laboratory has a mechanical prototype shop, heavy textile shop, parachute shop, and an experimental analysis branch which provides a capability to design, fabricate, and conduct laboratory testing of prototype components and systems. Examples include survival vests, field hygiene equipment, various types of shelters, and parachutes.

The **Operations Research and Systems Analysis Office** is a major contributor to the DoD Food Program, which is administered by NLABS. To date this office has achieved improvements in military food service systems and operations for each of the military services in the areas of garrison food service, combat food systems, food service personnel systems, and management techniques and procedures. These improvements represent savings in the number of military food service personnel utilized and dollars expended, at the same time improving military customer satisfaction, meal attendance, and nutrition.

In the future, this office is scheduled to undertake systems analyses and designs aimed at both near and longer term improvements in an increasingly broader range of military food service systems.

Facilities Up To Date

Natick's facilities are some of the best in the world and reflect the most modern, up to date technology available. For example, the **Aero-Mechanical Laboratory** has a drop test facility, a horizontal impact testing machine, and a parachute prototype shop. The Individual Protection Laboratory has a footwear/leather facility, design shop, rubber compounding and evaluation lab, and a textile engineering laboratory. A pilot plant for foods and food processing, experimental kitchens, and a packaging laboratory are just part of the Food Engineering Laboratory, while the Science and Advanced Technology Laboratory has analytical chemistry and microbiological laboratories filled with sophisticated instruments and equipment.

Figure 4

Retort Pouches Significant Advance

Recent advertisements for a variety of entrees being sold in little pouches which need no refrigeration (just keep them on your shelf until you're ready to cook them, then drop them into boiling water) point to another Natick development. First suggested in the late 1940's by a Natick scientist, it was not until the mid-1950's—following the development of new plastics and adhesives by the chemical industry—that the Army allocated money for studying this system. Hailed as the most significant advance in food packaging since the tin can, the U. S. Department of Commerce predicts a $68 million market for food specialty firms.

Meals To Go

Developed for use at isolated installations such as missile sites, flight lines, or other places without kitchen service, was a Hot Meal Dispensing Unit. It is the only device of its kind in existence and permits the customer to select up to three components of a meal and have them heated and dispensed in less than three minutes. The prototype developed holds packaged, precooked food components in the frozen state, delivers selections to microwave ovens for heating, and releases them to a retrieval shelf. A unique feature of this unit is the incorporation of multiple small hot air jets into the oven cavity so that, when directed at the food from above, they provide a crisping effect to french fries, fried chicken, etc.

Personnel Protection Effective

Kevlar body armor (Figure 4) is another feather in NLABS' cap. Originally developed by Dupont and used as an automobile tire cord, Natick researchers picked up on Kevlar's use for lightweight body armor. It has gained such wide acceptance by the civilian population that virtually all VIPs wear one form or another of it for protection. You now can purchase Kevlar lined raincoats, sports jackets, golf jackets, and even Kevlar bras. Police officers wear vests that are as thin as undershirts, and to date over two hundred lives have been saved by these items.

Air Development From 2 Miles Up

HAARS—the High Altitude Airdrop Resupply System—is a two stage parachute system that permits the airdrop of

container loads of equipment and supplies weighing up to 2000 pounds from altitudes up to 10,000 feet. Airdrop at higher altitudes is possible, but the higher one goes the greater the reduction in accuracy. This system consists of a first stage 60 inch pilot chute to stabilize the container load; an electrobarometric sensor to measure altitude and to initiate deployment of the 64 foot second stage (recovery) parachute; and a flexible cargo container. With this system, the container descends at speeds up to 250 feet per second during the first stage. At an altitude of about 750 feet, the second stage parachute is deployed. This second stage parachute is sized to result in a normal impact velocity of about 28 feet per second. Airdrop is normally conducted at aircraft speeds between 130 and 150 knots. Aircraft now can resupply troops from altitudes which provide the aircraft with minimum risk of damage from small arms fire and shoulder launched ground to air missiles.

Soy Savings

One of the Food Engineering Laboratory's most significant cost saving accomplishments resulted from its adoption of ground beef extended with soy protein concentrate as the standard ground beef item for government procurement. After several years of review and experimentation, analysis of in-house and industry data, production, testing, and procurement document preparation, the Food Engineering Laboratory set the standard of 20 percent of soy concentrate by weight in ground beef. Soy concentrates are used to avoid any undesirable flavors and to provide highly nutritious products. This resulted in a savings of over $12½ million during FY 1980 and, based on the escalating cost of beef, the savings will become even more pronounced.

Technology Transfer To Civilian Use

Many of the projects and developments that come out of Natick Labs can be used as is or modified for civilian use. The Kevlar body armor and retort pouches are prime examples. However, the following example involved not only NLABs but other Governmental agencies and industry.

As a result of a request from the Office of the Surgeon General and personnel at Walter Reed Army Medical Center, a developmental effort was undertaken to produce flavorful **dental liquid** products for patients with broken jaws. Patients whose jaws have been wired together cannot eat solid food for a relatively long period of time. Patients were limited to diluted, strained baby food, milkshakes, egg nogs, and high protein (soy based) milk drinks. The diluted baby foods are very unpalatable, and patients quickly tire of sweet milkshake type drinks. As a result, weight loss is common and nutritional deficiencies may occur.

A program was instituted to develop flavorful products for the feeding of these patients. The products—termed dental liquids—must have an extremely small particle size (½ mm) and be easily sippable through a straw. A decision was made to formulate the liquid products so that they would taste like the items found in a normal diet. An initial problem encountered in developing them arose from the extremely small particle size requirement. This requirement is necessary not only so that the patient can ingest the food through a straw, but also avoid food particles from sticking to the wires in the patient's mouth.

Small Particles Gritty

Reducing fresh meat to such small particle size resulted in a product which had a gritty, grainy texture. While this could be largely overcome by the use of a double stage homogenizer, the purchase and use of such equipment was considered impractical, particularly for small hospitals. It was found that cooked freeze dehydrated meat could easily be pulverized to a fine powder with either a vertical cutter-mixer or a food blender. The use of the pulverized freeze dried meat thus enabled the development of a smooth liquid drink which was still relatively high in meat protein.

In all, eighteen dental liquid entrees were developed including seven beef, five chicken, three ham, and three pork items. These products are frozen in advance of their need, reheated in an oven prior to eating, poured into a cup for serving, and ingested through a straw.

The development of such a large variety of entrees was designed to avoid the boredom factor found in diets previously fed to patients with broken jaws. The inclusion of some highly seasoned items also helps to provide more interesting meals.

As a result of a press release and television news coverage, knowledge of the dental liquids has spread to the

public. This has resulted in the receipt of many inquiries for procurement of the products. In addition, inquiries have been received regarding the use of these products for feeding geriatric patients who lack the muscle control necessary for swallowing, oral cancer patients, patients with hiatal hernias, and those who have gone through dental surgery. NLABS is conducting further developmental work to produce dry mixes which can be made into dental liquids ready for consumption immediately upon the addition of hot water.

Two-Way Street

Technology transfer is a two way street, as one special project illustrates. The use of ballistic Kevlar fabric (the same Kevlar mentioned earlier) was applied to the development of a wide variety of ballistic protective garments with the primary emphasis on optimizing the comfort and construction of (1) Ballistic Protective Undershirts which incorporated 8, 9. 16, and 18 plies of Kevlar in the front, back, and sides to provide protection against handguns up to and including the 9-mm cartridge and (2) Women's Ballistic Protective Undergarments to include bulletproof seam construction. All funds for this work were provided by non-Army sources, and over 30 institutions were involved. These institutions included such agencies as the FBI, Secret Service, National Bureau of Standards, International Association of Chiefs of Police, and 13 police departments—one of which was the Royal Canadian Mounted Police.

Through this work, the Army gained considerable technical information and expanded its state of the art—all of which is directly applicable to Military Body Armor. Examples of some of these benefits were

- Improved methods for designing and constructing garments
- Increase of the competitive base and industrial capability to manufacture large quantities of Kevlar Ballistic Cloth and body armor
- Accumulation of additional data on the psychological effects of wearing body armor.

Army Leads in Expertise

As a result of this gain in technical information, the Army has maintained its position as the Department of Defense lead service and lead government laboratory for body armor expertise. The civilian community benefited also.

Prior to the development of this soft, lightweight body armor for commercial use, there were a relatively small number of manufacturers producing fabric armor materials and body armor items. Now, there are about ten companies producing ballistic materials and at least thirty organizations involved in the design, development, production, marketing, and distribution of commercial body armor. This has started a new industry and has created opportunities for large and small business and employment in every area in the country. And the growth rate is continually increasing. Also, organizations now are engaged in sales to foreign countries, which will contribute to a higher export of U. S. made products.

Under the Public Safety Officers Benefit Act of 1976, $50,000 is granted to families of personnel who are killed on duty. With over 200 known lives of police officers already saved by Kevlar body armor, this represents a substantial sum, in addition to the lives themselves, which are priceless. With the larger quantities of body armor being sold and purchased, quality has been improved while the unit cost has been reduced.

Planning Oriented To User

Planning is not taken lightly at NLABS; its purpose is to ensure that the developers will be able to respond to stated needs of military users—needs on which some progress has been made or needs that require a new approach. An example of one on which progress has been made but which is a continuing need is that for ever increasing protection against fragmentation weaponry. A need that requires a new approach is one that has emerged as a result of an advance in warfare that challenges the defense because there is little or no technical base to counter it—for example, the laser beam, of which the potential for destruction is enormous.

Planning of tasks within the limits of the NLABS mission is oriented toward the user, as stated previously. Planning efforts are consistent with the Science and Technology Objectives Guide (STOG) and the Base Technology Program related to Battlefield Systems (BTPBS). The latter plan is expressed in the form of SPIDER charts, SPIDER being an acronum for Systematic Planning for the

Integration of Defense Engineering and Research. Figure 5 shows an example of the chart which relates to the work being done on the DOD Food Program.

SPIDER charts are organized into three major divisions: the system, the subsystem, and the subsystems areas.

It is this type of planning that has led to important contributions, such as ready to eat meals, camouflaged uniforms and equipment, fire resistant clothing, and portable tactical shelters.

"Group" Holds Fort At Natick

The Natick facility hosts several other governmental agencies whose activities often interrelate with NLABS activities, such as the U. S. Army Research Institute of Environmental Medicine, The Navy Clothing and Textile Research Facility, the Army Communications Command, the Army Health Clinic, and the Atmospheric Sciences Laboratory—Maynard Meteorological Team. A cooperative testing effort exists among these agencies and there is a constant interchange of developmental information. For example, the Communications Command provides all the electronic communications services for the "group", while the Health Clinic provides all the medical care, and the Met Team provides all the meteorological services.

As you can see, the slogan "We're Making Things Better" is very appropriate for Natick Labs.

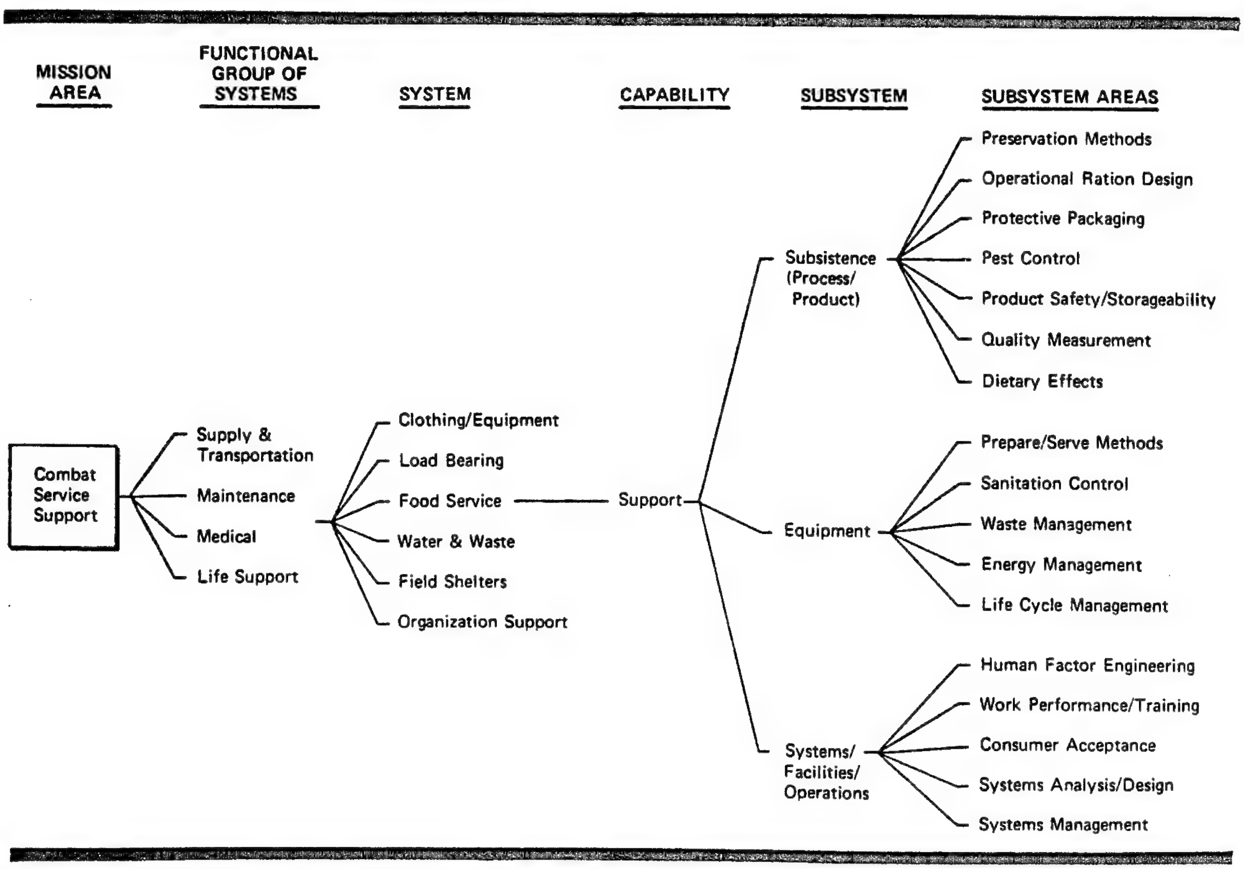
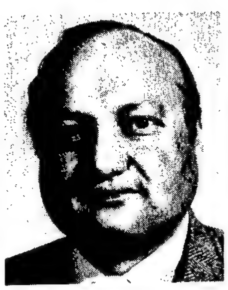


Figure 5

Signal Processing Technology the Key

Armaments Testing Data Computerized



LEONARD S. GOLDSMITH is Manager of the Automation Technology and Signal Processing Section and Post Deployment Software Support Center at ARRADCOM in Dover, N.J. After joining ARRADCOM in 1962 following his graduation from Knox College with a B.S. in Mathematics, he received his Masters Degree in Computer Information Control Engineering from the University of Michigan in 1974. Mr. Goldsmith held continually more responsible positions in automation control engineering, directing its application to signal processing and battlefield automation. He is a member of Tau Beta Pi, Eta Kappa Nu, and Morris County Engineers, and he serves as the Computer Resource Manager for Battlefield Automation at ARRADCOM.

During a four year in-house project carried out by the U.S. Army Armament Research and Development Command, a long step was taken in the advancement of technology from older manual methods of data reduction that used hundreds of feet of oscillograph paper. This notable stride forward was based upon readily available signal processing technology. Results stressed the accessibility of test data heretofore unknown.

Human Error, Skills Reduced

In 1972, manually processed variables (analog data) obtained from acceptance testing of various nuclear and nonnuclear armament items were costly, subjective, time consuming, and susceptible to human error. Highly skilled professionals were required to collect and reduce the data.

Therefore, this project was initiated to improve the production process by reducing the cost and delays associated with test data reduction and analysis. This thereby would allow timely adjustments in production of like items and minimize the high rework costs associated with the continued production of defective items.

The primary objective was to determine the causative factors contributing to the problem and to develop processes and hardware to minimize those factors. Of major concern was the responsiveness and accuracy of the test data reduction process, followed by the need to obtain and apply technologies to improve the signal processing concepts.

The prototype system was designed with the capability of handling all kinds of data, including real-time and nonreal-time test data from various types of input media. This meant that the system had to be capable of handling the then common media such as analog magnetic tapes of all designs and also the emerging forms of video and digital data. It was intended that the flexibility of the system concept and hardware would be great enough to handle any new type of data input characteristic of future testing. The system concept provided for

1. The real-time acquisition and feedback of data to the local test site facility from a central processing site.

2. The time dependent acquisition and transmission of data via analog magnetic tapes to the central facility in situations where the technology did not permit practical real-time acquisition and retransmission of the processed data.

3. The manipulation of conventional type of data as well as telemetry data, and new and emerging technology associated with projectiles and armament items.

NOTE: This in-house manufacturing technology project that was conducted by the Test & Instrumentation Division was funded by the U. S. Army Armament R & D Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Mr. Leonard S. Goldsmith, (201) 328-4955.

The Heart of the System

The center of the system was the control process computer. At that time, it was conceived that the largest computer available would be the best for the job due to the requirements to process large data arrays. The constraints of funds, approvals, physical space, manpower, and air conditioning influenced the decision to acquire a Scientific Control Corp (SCC) Model 4700 computer. This computer possessed a high dynamic bandwidth capability able to receive better than 500,000 samples per second of incoming data. Also, it had the ability to simultaneously transfer 500,000 samples per second of data to external devices. This computer's ability to perform these operations on each of four ports made it extremely versatile in handling input and output data, and its memory capability of 32,000 words (16 bits wide) of data with a capability to expand to 64,000 words via a memory map was revolutionary at that time. The computer stored data on either a fixed head magnetic disc for rapid storage and transfer of data or a movable head disc for the storage of programs and/or intermediate results. The brain of the system was the SCC Model 4700 computer coupled with its large complement of available peripheral equipment such as high speed magnetic tape drive, control console, card reader, line printers at either 300 or 600 lines per minute, and high speed paper tape reader and punch.

Optimum System Determined

The implementation of a preliminary system for the automated data acquisition and signal processing of armaments test data requires a translation of system specifications into a final operating system which satisfies defined criteria. The initial phase of implementation required the construction of a functional design of the proposed system. The functional design contained a schematic or graphical representation of the data acquisition and signal processing system, and showed all the system inputs and outputs, together with their required interconnecting transfer functions and timing diagrams which showed the time dependent sequence of events as they would occur in the proposed system. The functional design was obtained as an iterative process; it represented a task oriented view of the system and explicitly showed all data paths which were hardware and software independent. The construction of a functional design was a necessary step to translate the specifications into a form appropriate for the engineering task implementation.

In the second phase of implementation, specific hardware and software components were selected. This phase was concerned with the development of the implementation design.

Since the functional design permitted several implementation designs, an evaluation was required to obtain the optimum design. The Data Acquisition Support System (DASS) (Figure 1), was determined to be the optimum system. The major criteria utilized for this decision included

- Ability to acquire both analog and digital type data
- Throughput rate for acquisition and transmission
- System flexibility
- Interfacing capability
- Availability of peripherals
- Cost
- Delivery
- Software capability
- Memory capacity
- Speed
- Maintainability, environmental factors
- Human factors
- Management policies
- Expansion capabilities.

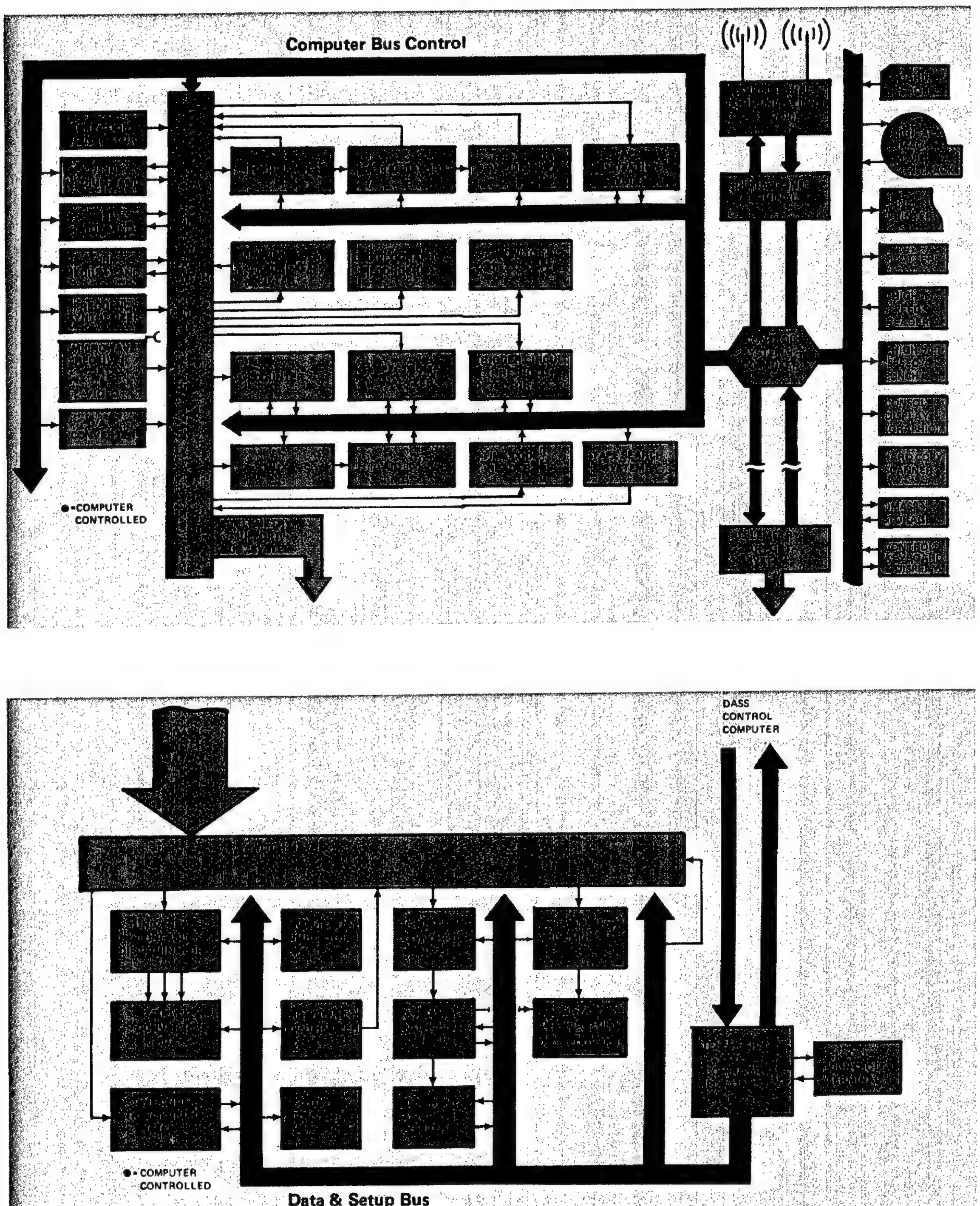

Computer Bus Control
●=COMPUTER CONTROLLED
DASS CONTROL COMPUTER
●=COMPUTER CONTROLLED
Data & Setup Bus

Figure 1

Two Systems Developed

To understand the objectives of the preliminary design, it is important to distinguish between real and nonreal-time data acquisition and reduction. Real-time acquisition and reduction is defined to mean the acquisition and processing of information in a timeframe short enough to be capable of affecting the test environment, should that be desired by the test engineer. In the case of long duration testing (e.g., monitoring of a slow rising temperature variable), real-time acquisition and reduction would result in the modification of the process environment or variables based on results obtained. In the case of functional testing of a munition item (e.g., 155 mm howitzer), real-time acquisition and reduction would mean the modification of the environment of the next piece of ammunition to be tested. This is the case, since the environment is usually unchangeable once the test is initiated. Nonreal-time data acquisition and reduction is the processing of data in a timeframe which does not permit the user to modify the test environment.

Two systems were developed (one evolving from the other) for the acquisition test data. The two systems differ primarily in that System I (DASS) transmits analog data to the central site whereas System II Test Module System (TMS), a DASS augmentation (Figure 2), digitizes the data on site and transmits digital data to the central site for processing.

To avoid problems resulting from the proliferation, duplication, and nonstandardization of computer programs, a central facilities approach was undertaken. All computer processing and data acquisition software was located and maintained centrally.

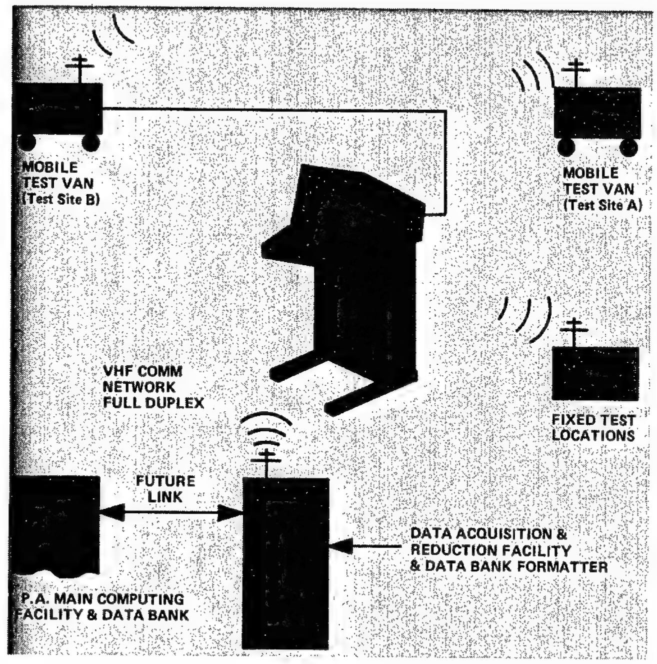


Figure 2

DASS Benefits Multiply

The Data Acquisition Support System (System I) objectives were to

- Reduce costs (instrumentation, manpower, etc.).
- Reduce quantity of items to be tested.
- Provide access by test user to computer system.
- Provide ability to monitor and, where possible, control test.
- Provide user calibration and on-line monitoring of test performance.
- Provide backup in case of system failure.
- Provide objective test information for data storage, retrieval, and analysis.
- Provide for video coverage when needed.
- Provide a test bed for continued development of automated processes.
- Provide automated method for the reduction of recorded media analog data.

- Provide modularity for system maintenance.
- Provide traceability and standardization of data reduction.

Raw Test Data Transmitted

To provide mobility to its test locations without sacrificing the bandwidth for testing communications, the DASS utilizes a microwave network for the transmission of both the video (where required) and analog test data. The microwave transmission network offers an overall 6 MHz bandwidth capability which, by means of frequency division multiplexing, can be subdivided to produce the subchannels required for the simultaneous transmission of the various analog (Baseband and FM-FM) or encoded digital (PCM, PAM, etc.) data channels. The information transmitted via the microwave link is raw test data from the test location to the central acquisition site. This information is received at the central site by a microwave relay link which is located on the ARRADCOM Drop Tower; it accepts data through its omnidirectional receiving (relay) antenna to the central site. Communications for purposes other than raw high bandwidth test data are handled by a Very High Frequency (VHF) Transmission System. The VHF network with bandwidth channels of 5 kHz are used for voice transmission when required, as well as transmitting full duplex digital information which is used to send reduced alphanumeric and graphic data to the test site and to transmit coordination and input data to the central site computer. The system can also be used to provide access by remote test locations to the main computing facilities for simulation and/or analysis purposes.

To provide backup in case of system failure, analog magnetic tapes are used to record all data transmitted over the microwave communications link. These same tape recorders provide the means to enter the data into the system once the system is again operational; also, they may be used as the vehicle for processing with nonreal-time applications and the dubbing of tapes which may have been recorded elsewhere.

The DASS is configured to handle multiuser requests utilizing the digital link and to acquire and process analog data on a time division multiplex basis.

Data transmitted to the system is routed by the control system computer (the system's brain) through the computer bus control (the DASS nerve system) to appropriate modules (the system's muscles) for signal conditioning purposes. This is accomplished simultaneously with the connection of the data to the multiplexor (MUX) and Analog-to-Digital (A/D) Converter where the analog data is digitized (14 bits plus sign at rates up to 500 kHz) and then transferred to the computer for processing. If the test to be processed requires any of the specialized equipment contained in the Telemetry Support Subsystem (TSS), the data is routed by the computer controlled switch (40 inputs by 60 outputs).

Once processed, the data is stored for future recall and analysis, and the reduced data in engineering units along with any graphical presentation required is transmitted over the VHF network to the test location where it is displayed for the engineer's use on the Cathode Ray Tube (CRT) Screen. A hard copy unit at the test site permits an immediate analysis of the data and provides a permanent record for the user's file. Should the user require extensive analysis of this data or wish to use the hybrid or large scale digital computer for simulation purposes, the central site can be augmented so that the terminal located at the test location can be utilized for this purpose. Once initiated from the test location, the request can be routed by the DASS to the hybrid or main computing facility.

Operational Characteristics

A test number is assigned to each type of test prior to its being conducted. A mobile van or fixed station with microwave communication equipment is stationed at the test site for the entire duration of the test. Prior to each test series, the operator enters a request to use the needed program along with the pertinent information relating to the test. This information defines the test location, type of test, and item to be tested, along with any free-form information defining test characteristics which would be of use to someone else reviewing the data. Upon receipt of this keyed information, the Acquisition System confirms that the test number is valid, stores pertinent data, and prepares to receive a request for service (RFS) from any test location about to begin testing. Since the duration

of the actual testing of armament items is usually short, the Acquisition System time division multiplexes between test locations. The system signifies its readiness to receive data from a given location by typing "Ready" and ringing a bell at the test site. Should the test not begin within a predefined period of time after the machine has indicated ready, the machine will print "Hold," causing the user to again issue an RFS while the system responds to any other pending RFS. The seeking process is performed by the DASS. Reduced data, once acquired, is transmitted in a predefined format to the user. Should a condition arise where a needed program is not available for immediate system use, the analog data is recorded and processed when the program becomes available.

To provide the response needed for a wide diversity of tests, the central site requires a large collection of highly specialized equipment whose cost is amortized over many users. Thus, the equipment located at the test site is kept to a minimum. Exclusive of the standard instrumentation, the test site system costs about $40,000 and consists of the microwave transmitter and mixer, a VHF transmitter and receiver, a graphics terminal with hard copy unit, and a modem.

Analog/Digital Processing Differs

The processing of analog magnetic tape on a computer system is considerably different from the processing of digital magnetic tape. This is due to the flexibility which the test engineer needs to respond to last minute changes in requirements. The last minute inability to utilize a given analog tape channel due to a malfunction of electronics may force the test engineer to reassign tape channel allocations to complete the test. Additionally, the starting and stopping of the tape recorder causes transient pulses which are indistinguishable from the true starting pulse; therefore, the data of interest could take up to two hours to locate when replayed at recorded speed, and it could be anywhere on the tape. It is for these reasons that the processing of recorded analog data is so different from live test data and, at present, it has no relationship to its digital tape counterpart. Many of these problems are eliminated by developing a device to put instructions and data for processing the tape on the recorded analog tape in machine readable form. Included are such items as channel allocations, test locations and conditions, test number, and other criteria which delineate the start and end of each test.

Disadvantages Identified

During the evolutionary process of implementing the DASS, two major disadvantages become evident:

1. It was found that multiple testing projects tended to conflict with one another in time and, therefore, required a high degree of coordination between users for successful operation.

2. The use of an analog transmission and recording medium limited the system accuracy to not greater than 5%, which sometimes masked the data being sought; i.e., recorded data can vary from actual data by 5% (amplitude and frequency).

An analysis of the armament testing being conducted indicated that test data acquisition requirements fell mostly into two categories; transient (short duration) and long duration. Whereas little could be done to eliminate the above mentioned system degradation without replication of costly equipment for long duration high data rate applications, technology was evolving which would provide a solution of the transient capture problem which was the predominant type of test being conducted. Implicit in transient capture applications was the need to acquire data usually at high rates in excess of 200 kHz, with an accuracy of up to one half of one percent. The duration for such a capture was usually short (less than 50 ms).

The introduction of low cost solid state memory and digitizers made possible the ability to accurately digitize and buffer transient information on site. In addition, the test engineer was given complete freedom from conflict with other tests proceeding simultaneously. This development led to the modification of the DASS through an augmentation to include the Test Module System (TMS). The latter device represented a modular digital approach to the acquisition of transient type of data as well as long duration low data rate applications.

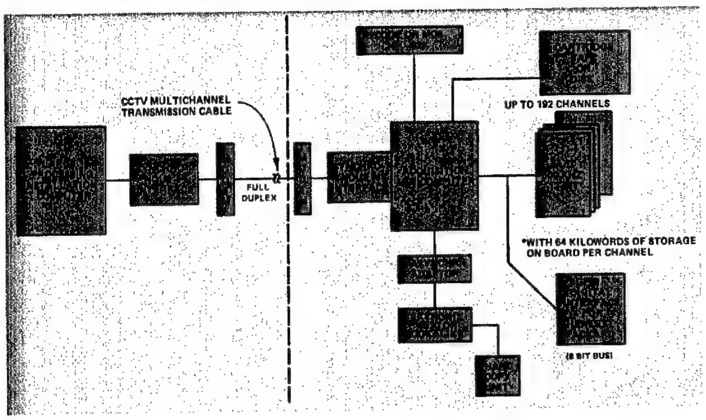


Figure 3

This system change incorporated all the features of the original DASS, including cost and bandwidth, and eliminated the disadvantages of reduced accuracy and inordinate coordination needed for transient capture application.

Test Module System Augments DASS

The TMS was designed as an augmentation of the Data Acquisition Support System (Figure 3), with the following objectives:

- Reduce testing costs (instrumentation, manpower, etc.).
- Reduce quantity of items to be tested.
- Provide address by test user to large computer system.
- Provide backup.
- Provide nonsubjective test information for data storage and recall.
- Provide modularity for system maintenance.
- Provide traceability and standardization of data reduction.
- Improve accuracy.
- Minimize system software.

Where transient (short duration-high frequency content) type data was acquired or where data rates were low, an inexpensive front end system was implemented. This TMS acts as an acquisition device with limited on-site capability and depends on the remote large scale computer DASS to provide processing. The acquisition terminal (TMS) performs three basic functions: to (1) act as the controller for all devices attached to it; (2) act as the device which can display quick-look information to confirm acquisition; and (3) act as the concentrator to send only the pertinent data to the large scale machine for processing.

Since these are the only functions which the minicomputer need perform, the minicomputer can have very slow memory (0.5 microsecond), and needs only a minimum of specialized programming support. The programs for reduction and analysis purposes are written for the large scale machine, DASS, and therefore can be coded in FORTRAN, which enables them to be transportable from installation to installation. The transportability feature is used to insure that similar tests, run at different installations, use the same programs, and hence provide similar results. Since the TMS could be configured to look like a standard terminal to the main processing computer (DASS), little or no operating system modifications were required to support this device. Communications is further augmented by a standard closed circuit television system with a multichannel, bidirectional transmission capability of a million bits per second (megaband) per subchannel. Further inroads in data collection and transmission are anticipated through the future use of satellite communications, with their expected availability and decreased cost.

Digital Reduction—Versatile, Unique

To determine the performance characteristics necessary to acquire, process, and reduce armaments test data, computer programs were written to process velocity, acceleration, displacement, vibration, acoustic pressure, temperature, infrared, laser, and aeroballistic data. Included as examples in the above were trajectory determination using pulsed and doppler radar and yaw sondes; pressure determination of in-tube and closed bombs; signature analysis of road vehicles, helicopters, and explosive devices; and vibration and impact analysis using strain gauges and accelerometers.

One of the most critical areas of concern in the acceptance testing of armament items is the true in-flight performance of projectiles. The device most commonly used to obtain this data is the yaw sonde, which is installed in place of a fuze in a projectile to obtain data on its nutation angles and rates. Heretofore, data obtained from yaw sondes was less than optimal. Due to the processing techniques employed, data was lost as a result of noise, inability to track data signals, and large dynamic motion of the data signal.

To obtain the in-flight performance characteristics of projectiles, a Hi-G (greater than 30,000 G's) telemetry device was installed in the projectile in place of the fuze. The telemeter receives data from two on-board sun sensors and transmits these low level signals to a ground station where the data is recorded. On completion of testing, the data is shipped to a data reduction facility. At the beginning of this project, yaw sonde data was processed via analog or hybrid computers. The use of a digital computer was not considered a viable approach at that time. To improve the quality of yaw sonde data contained in the telemetered signal, a program was written on the DASS to acquire, process, and digitally filter the data. As a result, virtually all present yaw sonde data is reduced digitally, with all ARRADCOM Dover site applications being performed in this manner. It is now considered the most versatile and unique method for reducing such data by test engineers in at least two installations.

This digital processing technique has considerably increased the ability to extract a meaningful signal from a high concentration of noise.

Expected/Unexpected Benefits

Not only have engineering hours been saved as a result of this project, but the quality of data has been improved also. Radar information is now obtainable for all rounds fired; subjectivity has been removed in the data analysis; manual manipulation of raw data has been eliminated; human errors have been reduced; and, most important, data is no longer lost. Reduction in delay in reducing data has been achieved materially, as have the analysis and retransmission in real-time. Telemetry communication of data as well as instructions is now possible and includes real-time feedback of information on the nature and reality of the test being performed. Savings and improvement are clearly evident. Less obvious has been the fact that the number of tests required can now be reduced and the number of experimental projectiles required to obtain factual information can be limited.

Of possibly the greatest benefit to manufacturing methods and technology is the identification of a production problem as the result of detection of a defective first item from a production lot by the rapid analysis of the item's flight characteristics. For the first time, any difficulties encountered in the flight of each round fired can be determined. Engineering modification then can be made to correct the production and thus prevent the continued production and stockpiling of potentially defective rounds.

Application of signal processing technology to yaw sonde data resulted in an unexpected benefit. The yaw sonde generates data from which the behavior of the projectile in which it is mounted can be deduced. The desired information or signal is not always evident in the display of data received from the device. The common terminology is that the signal is buried in the noise. In the past, such data was considered worthless and had to be discarded. Now, through the use of digital signal processing technology, it has been found that the data can be manipulated to extract the signal from the background electronic noise. This process is considered the most versatile and complete method for reducing yaw sonde data to date.

New vistas in the analysis of radar returns have resulted as an equally major unexpected benefit. The ability to nonsubjectively and rapidly reduce radar returns provides entire flight history including hardware security (external parts failure) of every projectile fired. Additionally, radar data was determined to be considerably more extensive than was being obtained. This project demonstrated that data such as spin, nutation, and precession rates could be extracted from radar data from unmodified projectiles in flight.

Of further value from this project was the design of the digital test module. It serves the purpose of removing from the test site substantial amounts of reasonably expensive test and instrumentation equipment for collecting and storing the data being generated by the test.

Condensables Make Up Small Percentage

Opacity/Particulates in Forge Exhaust

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Photograph

Unavailable

Particle concentration from exhaust emissions at forging shops around the country now may be determined accurately by measuring the optical density or opacity of exhaust, following completion of a 21 month manufacturing technology study by JACA Corp. for the U.S. Army Armament Research and Development Command. Test results indicate that a strong correlation does exist between particle concentration and optical density at the 95% confidence level. Through a least squares linear regression analysis of data points, the best-fit line for the total data base is defined. Eighty three percent of the variation of optical density values can be attributed to variation in particle concentration. Variations in particle size distributions account for a portion of the remaining 17%

Although the study was concerned primarily with the Erie press line at Scranton Army Ammunition Plant, the information generated supports the use of an empirical relationship for other forge shop exhaust. A final recommendation was that the average opacity values over periods of 1 hour or more should be corrected to account for the difference in stack diameter between a given forge shop exhaust and the Erie press line exhaust. Once the corrected average opacity is converted to optical density, an estimate of particulate concentration may be obtained.

Uncontrolled Exhaust Analysis A First

The major effort of the 21 month study was to perform a technical evaluation of the uncontrolled exhaust from the Erie press line at the Scranton Army Ammunition Plant (SAAP) operated by Chamberlain Manufacturing Corporation. Technical evaluation consisted of performing numerous particulate emission tests concurrent with the operation of a transmissometer, as well as analyzing process operating conditions. To evaluate emission and process characteristics at different forging facilities, two additional forge shops were visited. Particulate emission and opacity tests were performed at the forging facility of Flinchbaugh Products, Inc., while process and opacity observations were recorded at the forge shop of Chamberlain Manufacturing Corp. in New Bedford, Massachusetts. These additional plant inspections provided a basis for evaluating emission characteristics between forge shops.

Since the emissions from the forging operations did not exhaust to particulate control devices before entering the atmosphere, it was not apparent that a correlation between opacity and particle concentration would exist. Several earlier studies at industrial facilities such as power plants, cement kilns, and asphalt plants had shown that a reliable correlation between opacity and particle concentration did exist. However, these studies were conducted on controlled exhaust streams following a control device. After the control device, the exhaust characteristics (especially particle size distribution) are likely to be much more uniform than an uncontrolled exhaust stream.

NOTE: This manufacturing technology project that was conducted by JACA Corporation was funded by the U. S. Army Armament Research & Development Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Mr. Joseph T. Clancy, (201) 328-3404.

Varying exhaust characteristics were thought to be the limiting factors in this study. Indeed, because of the possibility of excessive variability of forge shop exhausts, the primary purpose of this study was to determine if an empirical relationship between opacity and particulate mass concentration could be established. The study was to describe this relationship for the purpose of estimating particulate mass emissions from opacity data recorded at similar forging operations.

Forging Process Involves 3 Steps

A brief description of the forging process is necessary to understand the mechanism by which emissions are generated. Although there are similarities among the forging operations, there are also striking differences which affect the emission characteristics and thus the reliability of the mass emission/opacity relationship.

The three forging operations that were observed manufacture large caliber shells for the United States Army. These sheels may have diameters of 155 mm, 175 mm, or approximately 200 mm. The forging presses are characterized as closed die type, where heated precut steel billets are formed to the desired shape through sequential mechanical operations.

The Erie press line at the SAAP is a three step process consisting of preforming, piercing, and drawing operations. The preforming and piercing steps use a punch and die arrangement to form a cavity in the hot steel billet and to shape the steel according to the dimensions of the die. A solid punch is forced into the metal, which is placed in a closed, cylindrical die cavity. This process produces a cavity in the steel billet by displacement without removal of the metal; in addition, the metal takes the form of the die cavity. Preforming and piercing are essentially the same type of operations, except that the punches which are used for each are shaped differently. The preforming punch has a blunt end, while the piercing punch is elongated and comes more to a point. The drawing operation is the last phase of the shell forging process. In this operation, the partially formed shell is forced through a series of rings by the drawing punch. This procedure elongates or draws the shell as it passes through the rings.

The Erie press line at the SAAP is totally automated, in that the shells are automatically moved from one process phase to the next. In addition, lubricating oil is automatically applied to the punches and the die cavities. Only one person is required to operate the Erie press line.

In contrast to the Erie press line, the forging process at Flinchbaugh Products, Inc. requires 7 or 8 people to operate. The Flinchbaugh forging process also consists of three steps: descaling, preforming and extrusion, and drawing. However, the process is different than the Erie press at the SAAP because the shell must be manually moved with manipulators from one process step to the next and lubricating oil is manually swabbed on the punch and die cavity. The manual nature of the Flinchbaugh shop limits production to approximately 60 shells per hour, while the SAAP Erie press line produces about 120 shells per hour.

Aerosols are generated during the forging process because of the lubricating oils which are used to prevent the hot metal from adhering to the punch and die cavity.

An additional characteristic of the forging emissions is that they vary temporally because of the cyclic nature of the process. Forging emissions are not continuous but are rather erratic, increasing and decreasing in both intensity and duration throughout the forging cycle. The temporal fluctuation is short term (with peaks occurring every 45 to 90 seconds) and regular, as long as the presses are operating properly. Emission peaks occur at each process step when the punch and oil come in contact with the hot metal. The emissions decrease and subside when an individual step is complete. Because there is more than one shell being processed at any one time, the resulting emissions are a mixture of particulates from the various forging steps. At each process step, the steel temperature and oil mixture may be different so that the resulting particulate emissions vary among steps and combine in the exhaust stack.

It is obvious that there are numerous parameters associated with the forging process which may affect the emissions at an individual forge shop and may cause emissions to differ between forge shops. These include shell production rate, steel temperature, type of lubricating oil, quality of lubricating oil, quantity of oil used, method of oil application.

Three Shops Visited

The major emphasis of this study was to determine the relationship between opacity and particle mass concentration at the uncontrolled exhaust of the Erie press line at the forge shop of the SAAP. This was done through

numerous field tests of both opacity and mass emissions. It was established early in the project that, of the six press lines at the SAAP, the Erie press line was most accessible and convenient for testing, and also, that it would be operating during JACA's testing program.

After the initial testing phase at the SAAP, it was decided that other forge shops should be visited to evaluate emission characteristics relative to those at the SAAP. Flinchbaugh Products, Inc. permitted JACA to perform particulate emission and opacity tests at their facility, because they were in need of the test information. JACA also inspected the Bedford, Massachusetts forge shops of Chamberlain, Manufacturing Corp., but no particulate emission tests were performed at this facility.

A total of fifty-seven particle mass emission tests were conducted during the study period. For all but two of these particulate test runs, opacity data was recorded during the entire test period.

JACA's initial assessment of the exhaust of the Erie press line at the SAAP consisted of four EPA Method 5 test runs and two particle sizing tests using a Brinks impactor. Opacities were recorded by a certified observer for all but two of the six test runs. Subsequent to the initial assessment, stack opacities were monitored with a single pass transmissometer (Datatest Corp., Model 90A).

Forty-five particulate emission tests were conducted at the Erie press line of the SAAP, while twelve test runs were conducted at the Flinchbaugh forge shop. Various test methods were used during this study because data on both particle size distribution and total mass concentration were required. The original plan was to conduct all particulate tests in accordance with EPA Method 5 testing procedures and that the impinger catch would also be analyzed. However, after the initial tests at the SAAP it was decided that an in-stack filter assembly could be used and the tests could be conducted in accordance with EPA Method 17 procedures. It was thought that more test runs could be conducted without compromising the test results. JACA did perform two additional EPA Method 5 tests at the Flinchbaugh forge shop to determine the compliance status of the facility relative to the emission regulations of the Pennsylvania Department of Environmental Resources. Whenever possible, the "front half" particulate catch and the impinger catch were both analyzed. The impinger catch was analyzed by chloroform and ether extracts (condensibles) as well as by 0.2 micrometer membrane filtration.

Testing Sites Differ

A primary concern in this opacity/mass emission study was to choose a sampling location where there was an adequate length of straight ductwork prior to the sampling ports. At both the Erie press line and the Flinchbaugh forge shop the choice of sampling locations was limited.

Figure 1 and Figure 2 illustrate the sampling locations at the Erie press line and the Flinchbaugh forge shop, respectively. For the Erie press line, the transmissometer was located downstream from the stack sampling ports. This was reversed for the Flinchbaugh forge shop. Both sampling locations were upstream of the exhaust fan. For all test runs (except the two Method 5 tests at Flinchbaugh) only one sampling port was used. The exhaust ducts were traversed parallel to the light beam of the transmissometer and twenty points were sampled for each test run. The sampling duration was 2, 3, or 4 minutes per test point, depending on the anticipated grain loading. Thus, test runs were generally 40, 60, or 80 minutes long. However, the EPA Method 5 tests at Flinchbaugh were 120 minutes long, because two sampling ports were used. In all cases, the transmissometer was operated over the entire stack testing period.

PARTICULATE EMISSION TEST

The results of the particulate emission tests at the Erie press line and the Flinchbaugh forge shop show consistency among the testing parameters at both press lines. The exhaust characteristics (such as flow rates, temperature, moisture, and gas analysis) are consistent and dependent on ambient conditions. The exhaust fan pulls large quantities of air through a hood which covers the entire forging process, so the exhaust is mostly ambient air. For the purpose of this study, several of the test runs were invalidated because of sampling or analysis problems.

The total particulate concentrations (gr/dscf) from both forging processes are quite low, considering the fact that the exhausts are uncontrolled. They range from 0.0094 gr/dscf to 0.0682 gr/dscf for the Erie press line and from 0.0052 gr/dscf to 0.0089 gr/dscf for the Flinchbaugh forge shop. Generally speaking, the emissions from the Flinchbaugh forge shop are much lower than those of the Erie press line at the SAAP, undoubtedly because of the

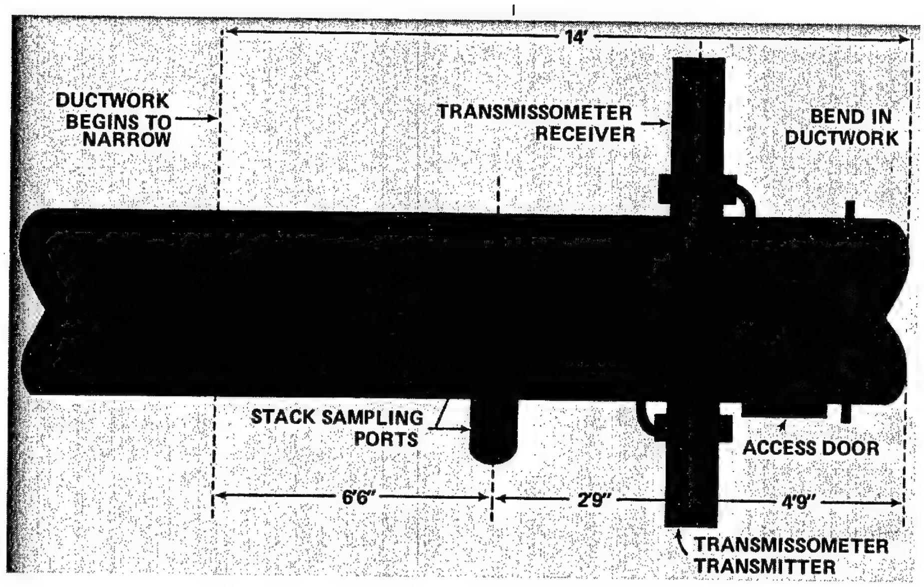


Figure 1

differences in the processes—i.e., production rate, type of lube oil, lube oil usage, etc.

For the most part, the condensible particulates constitute a small percentage of the total particle concentration. The condensibles average approximately 7.3 percent (range 0 to 50.6%) of the total particulate weight for the Erie press exhaust and 11.2 percent (range 1.6 to 27.7%) for the exceeded 20 percent (as high as 50.6%), but there was no obvious reason for these anomalies. For the purpose of comparison, JACA's average emission concentrations were separated according to the testing procedures used to determine the concentrations.

Results from the Erie press line compare favorably with the test results from other press lines at the SAAP (Verson, John Deere, and Bliss #1 press lines). Average emission concentrations at the Erie press line are on the order of 0.0233 gr/dscf to 0.0368 gr/dscf, while particle concentrations from the Verson, John Deere, and Bliss #1 press lines are 0.0318 gr/dscf, 0.0298 gr/dscf, and 0.0206 gr/dscf, respectively. At the SAAP, each press line uses the same type of lubricating oils (Quenchtex 500 and Texaforge 7571). According to SAAP personnel, the two lubricating oils are mixed in the dip tanks and the Texaforge 7571 lubricating compound (referred to as "hot punch") is applied to the die cavity. Both lubricating compounds are oil based, and the Texaforge 7571 contains a graphite additive (approximately 25%). The average production rates (shells per hour) of the four presses at the SAAP are also comparable (105 to 127 shells per hour), but the Verson press has a greater material throughput (pounds per hour) because it manufactures larger shells.

The particulate test results from the Flinchbaugh forge shop show average concentrations of 0.0052 gr/dscf to 0.0086 gr/dscf, which are one third to one fourth the concentrations from any of the forges at the SAAP. However, the Flinchbaugh test results are similar to the test results from the Chamberlain Manufacturing forge shop in New Bedford, Massachusetts. The average emission concentration at the New Bedford forge shop was tested to be 0.0058 gr/dscf. The lubricating oil used at Flinchbaugh is designated as Hot Forging Agent 201 (HF 201) manufactured by E. F. Houghton and Co. This lubricating compound is oil based (approximately 50 to 65% oil) and contains 20 to 30 percent graphite. The lubricating compounds used at the New Bedford forge shop are designated as MacForge 599 and MacForge 958. MacForge 958 is water based, containing 12 percent oil and 24 percent graphite. MacForge 599 is oil based, with 48 percent oil and 30 percent graphite. A mixture of MacForge 599 and 958 is used in the dip tanks, while only

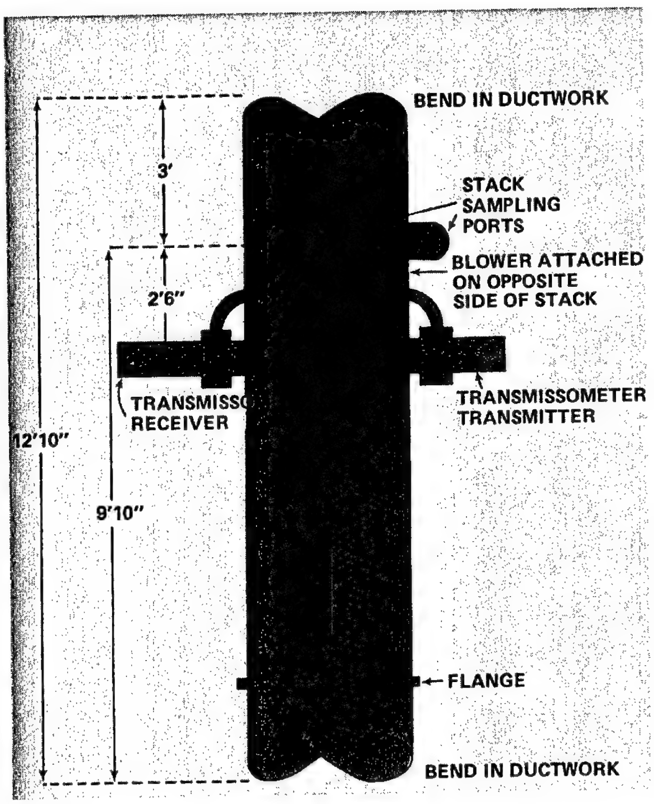


Figure 2

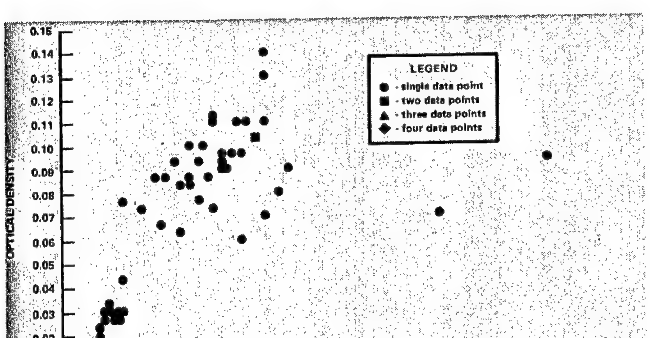


Figure 3

MacForge 599 is used for swabbing the die cavity. The production rates are dissimilar for the Flinchbaugh and New Bedford forge shops.

No conclusions can be drawn about which process parameters are most important relative to the exhaust emission characteristics. It appears that the production rate and the quantity and type of lube oil used have a significant effect. Most probably, a combination of process factors (including production rate, oil usage, method of oil application, etc.) account for the observed emission characteristics. This indicates that the particulate emission characteristics may vary from one press line to another, thus any relationship between mass emissions and opacity is likely to be site specific.

OPACITY OBSERVATIONS

As previously discussed, each of the particulates mass emission tests was accompanied by opacity data which was recorded over the entire test period. For the most part, opacities were monitored with a Datatest Model 90A transmissometer. Analysis of opacity data was straightforward; opacity values were obtained from the recorder charts and averaged over the sampling period for each test run. The Flinchbaugh opacity data exhibited a regular pattern of maximum and minimum opacities and a continuous curve. In this case the average opacity was determined by measuring the area under the curve with a planimeter and dividing by the total area for the entire test period. The opacity data from the Erie press line exhibited an erratic pattern and did not show a continuous curve. Since the chart recorder used pressure sensitive paper, the Erie press data exhibited a series of distinct dots (approximately 60 per minute) which varied considerably. The opacity data from the Erie press was analyzed by counting and recording the magnitude of the individual dots. The average opacity during a test period was simply the sum of the magnitudes of the opacity values divided by the total number of points which were counted.

It should be noted that the Flinchbaugh opacity data was also adjusted to account for the difference in emission characteristics and stack diameter between the Flinchbaugh forge shop and the Erie press line exhausts.

The exhaust of the Flinchbaugh forge shop exhibited average opacities (corrected) in the range of 4.68 percent

to 9.67 percent, while the Erie press line exhaust showed opacities in the range of 13.20 percent to 27.63 percent. Obviously, the opacity values at the Erie press line are consistently higher than those at the Flinchbaugh forge shop. The particle concentration values follow this same general pattern.

Optical Density vs Mass Emissions

The main emphasis of this study again, was to relate optical density with particle mass concentrations. JACA chose to represent the mass emissions in terms of grains per actual cubic feet of exhaust gas (gr/acf), instead of on a dry standard basis. The reduction of the particulate data to a dry standard basis artificially alters the concentration values due to differences in stack moisture, temperature, and pressure. For example, two stacks may exhibit identical particle concentrations when expressed as gr/acf. However, if one stack has a moisture content of 10 percent by volume and the second has a moisture content of 5 percent by volume, the first stack will exhibit a higher mass concentration than the second if the moisture alone is removed from the calculation. The mean spectral response of the transmissometer is in the range of 500 to 600 nm. There are water and carbon dioxide absorption bands in the near infrared region of the light spectrum (i.e, 1,000 to 2,500 nm). Large opacity measurement errors could result for stack gases with high humidity due to the light absorption band of water. However, measurement errors due to the presence of water and carbon dioxide do not present a problem in this study, because these compounds are almost negligible in the exhausts examined.

To compare the average opacity or optical density values obtained at the Flinchbaugh forge shop to those from the Erie press line at the SAAP, the opacity values for Flinchbaugh were corrected or reduced to an equivalent basis. This takes into account the differences between the stack diameters and the particle characteristics at the two forge shops. While the corrected or equivalent opacity values for Flinchbaugh were used in the analysis of the total data base, the uncorrected opacity values were used when only the Flinchbaugh data was analyzed.

The relationship between optical density and total mass concentration was established through computer analysis. Data was analyzed by the use of the Statistical Analysis System's General Linear Models Procedure, which is a least squares linear regression model. Basically, this analysis scheme generated the "best fit" line passing through 0 for the data sets and tested the significance of the relationship between the optical density and mass concentration values.

To evaluate the differences between the Flinchbaugh and the Erie press line data and to determine if the test methods may have an effect on the study results, the total data base, as well as subsets of the total data base, were analyzed. Eight different scenarios were considered in the analysis scheme. For all eight data sets which were analyzed, the results indicate that there is a strong correlation between particle concentration and optical density. This correlation was supported by the statistical parameters.

For each of the eight data sets, two graphs were generated. These two graphs, for each data set, were plotted on a single page for ease of comparison. The top graph (Figure 3) on each page represents a scatter plot of the particle concentration and optical density values contained in the data set. The bottom graph (Figure 4) on each page represents the best fit of data in the graph at the top of the page by a least squares linear regression analysis. This linear model essentially predicts optical density values from particle concentration values so that the best line is constructed relating the two variables. For these analyses, the best fit line was forced to go through the origin, since it is obvious that optical density would be zero if there were no particles in the stack at the time of measurement.

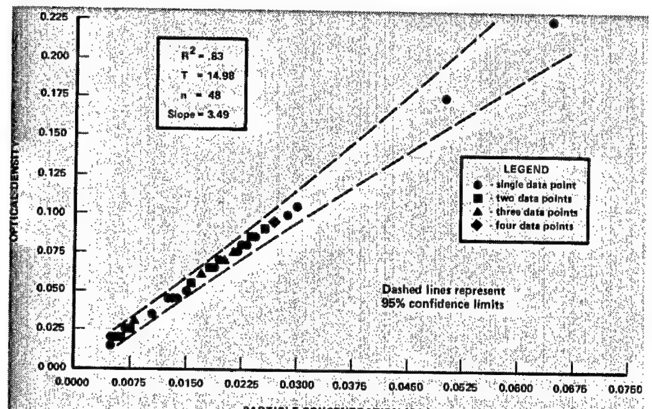


Figure 4

Electrooptics Upgrade Past Technology

Cannon Chambers Profiled Faster

STEPHEN J. KRUPSKI is a Metrology engineer with the Quality Engineering Division, Product Assurance Directorate, Watervliet Arsenal. He currently is assigned as Project Manager on the Army's New 120 mm Tank Gun. Responsibilities include development of the Government's Inspection Plan and accompanying equipment for this new cannon. Mr. Krupski has been involved as Project Engineer on several materials testing technology funded projects involving application of nondestructive testing techniques to inspection of cannon components. He is a 1974 graduate of Rensselaer Polytechnic Institute with a B.S. in Mechanical Engineering.

Photograph Unavailable

Chamber profiles of 105mm M68 cannons are now measured quickly and accurately following completion of a manufacturing methods project by the Product Assurance Directorate at Watervliet Arsenal. The work was sponsored by the U.S. Army Armament Material Readiness Command. The system developed advanced inspection capabilities markedly; however, utilization of a master cam of complex configuration increased the expense of the system—it was mandatory because of the extremely close tolerances that must be maintained. It is hoped that upcoming required designs for inspection of the 120mm XM256 cannon chamber will develop a successful system requiring no complex master cam, or at least one of simpler configuration.

Physical Tolerances Stringent

The 105mm M68 cannon fires fixed ammunition that utilizes brass, steel, or aluminum cartridge cases. The cases are thin enough to be expanded by the pressure released from the burning propellants to form a tight fit against the tube chamber wall, thus preventing rearward escape of gas (obturation). Subsequent to firing, the cases relax sufficiently to facilitate case extraction. Among problems caused by out of tolerance conditions in the tube chamber are: lack of obturation, difficulties with chambering the ammunition, and/or difficulties with case extraction. The chamber of a gun tube consists of a series of intersecting conical and cylindrical surfaces, which require stringent locational and diametrical tolerances. A gaging system is required to accurately and precisely record the actual profile of the chamber without interpretation and recording by an operator.

The system developed under this project by Watervliet Arsenal utilizes electronic and optical measuring techniques in a mechanical assembly to drive a digital display and printer for recording total part configuration.

NOTE: This manufacturing technology project that was conducted by the Product Assurance Directorate at Watervliet Arsenal was funded by the U.S. Army Armament Command, Rock Island Arsenal, under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRCOM Point of Contact for more information is Mr. S. K. Krupski, (518) 266-5697.

Past Technology Not Good Enough

In 1960, Watervliet Arsenal designed gages to inspect the then new 105mm M68 chamber. Four plug gages were designed which utilize a fixed diameter disk to verify chamber taper by measuring how far this disk can be fitted into the tapered zones. Also designed was an air tracer gage. This tracer gage utilizes air cartridges which track along the chamber wall and measure the distance from the chamber wall to a master template that is positioned in the chamber by the gage body. This tracer gage can effectively measure the entire chamber while the operator views the level of floats in two air column readouts. Although it has been used for many years, this gage has several shortcomings.

First, the gage must rely on shop air supply which has proven to be unreliable with regard to moisture content and purity. Second, determination of the distance that the tracer tips have traveled into the chamber (from the rear face of the tube) is a cumbersome procedure; it is not applicable to the current standards of accuracy and repeatability. Third, the readout system provides only a visual float level as an indicator of component size; as a result, the only inspection records available are notes the inspectors might make.

An update system has been developed to take advantage of the state of the art electrooptical measuring systems. With the new system, air is not required for operation—air cartridges are replaced with electronic cartridges. Also, downbore distance is measured by an optical scale. A printer records both chamber size and downbore distance to provide a complete inspection record.

Higher Level of Quality Required

The electronic tracer system for cannon chambers must be able to completely measure the chamber of a 105mm M68 gun tube. The new system should duplicate the inspection quality of the existing tracer air gage, yet must add the capability to overcome the air gage's shortcomings. It was required that the basic gage fixture be similar in design to the proven air gage concept. Modifications were permitted as necessary to incorporate electronic (LVDT) cartridges in place of the air cartridges and to incorporate a high accuracy downbore measurement system. A remotely controlled printer was required to print out both deviations from basic drawing dimensions and the downbore location of the deviations.

The following section describes the new chamber profile measuring system as developed under this project.

The New System Computerized

The system consists of two units—an electronic control/data processing unit (console) (Figure 1) and the cannon chamber gage (gage assembly) (Figure 2).

The gage assembly contains a master tool steel template scaled 1:1 to the longitudinal cross section profile of the M68 chamber. Two radially opposed position sensors (LVDT's) measure the difference in a cross-sectional diametrical plane between the master template and the chamber under inspection. A linear scale senses the down chamber location of the position sensors with respect to the rear face of the tube (RFT).

The linear scale consists of a glass incremental grating scale and a traveling reading head. The reading head transmits light from a miniature filament lamp through the optical grating scale to two pairs of photodetectors on the opposite side. As the head moves, it generates two signals, each of which is a close approximation of a sine wave. One signal train is displaced 90 degrees in phase with respect to the other. This permits detection of direction of travel with the proper electronics.

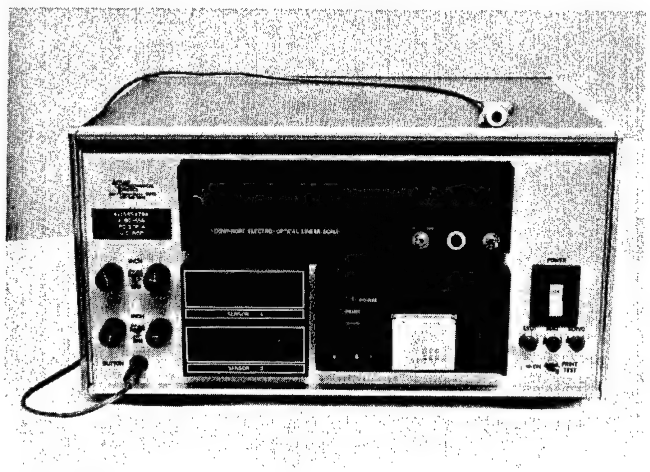


Figure 1

Special Features of the Gage Assembly

1. Micrometer controlled down chamber positioning of master template to allow registration with the chamber under inspection.

2. An electromechanical drive system for positioning the LVDT carriage in the chamber with a pressure sensitive "stiff stick" for infinitely varying the rate of travel from zero to maximum. (A manual vernier

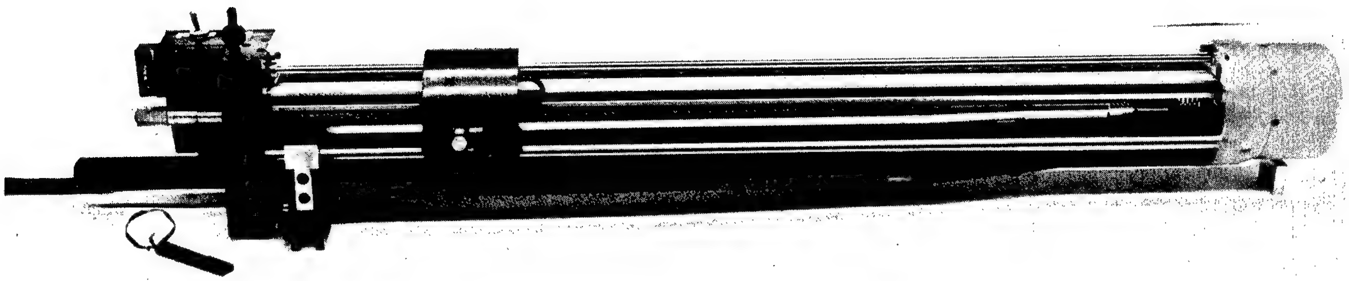


Figure 2

control is incorporated to permit fine position setting. See Figure 3.)

3. Magnetic holding for securing the gage assembly against the RFT, eliminating the need for operator hand steadying of the gage assembly.

4. A builtin mechanical gaging station containing two reference surfaces with a known diametrical separation. (This serves as a builtin set check.)

The console contains the necessary amplifiers, counters, and a BCD converter for driving the seven segment display and the printer. The console contains the following:

- Continuous display of the output of each LVDT with .0001 inch resolution (each readout has an adjustable electronic zero.)
- Displays that are independently switchable from customary (inch) units to metric.
- Continuous display of the downbore distance with .0001 inch resolution. (This display may be reset at the touch of a button to "0" at any location or to a preset valve set by thumbweel switches.)
- Cable connected manual pushbutton control commanding the printer to start. (The front panel also has a switch to perform this function. Upon command, the displayed LVDT valves and the downbore distance reading will be printed.)

Gaging System Found Acceptable

Testing of the system to ensure proper performance (and conformance to the specifications) was accomplished in the setting check used for the air gage and in an actual 105mm M68 tube chamber. The setting check was used to verify centering of the measurement transducers with respect to the support points of the gage body (Figure 4). Using standard measuring techniques, the master cam template was disassembled from the gage body and

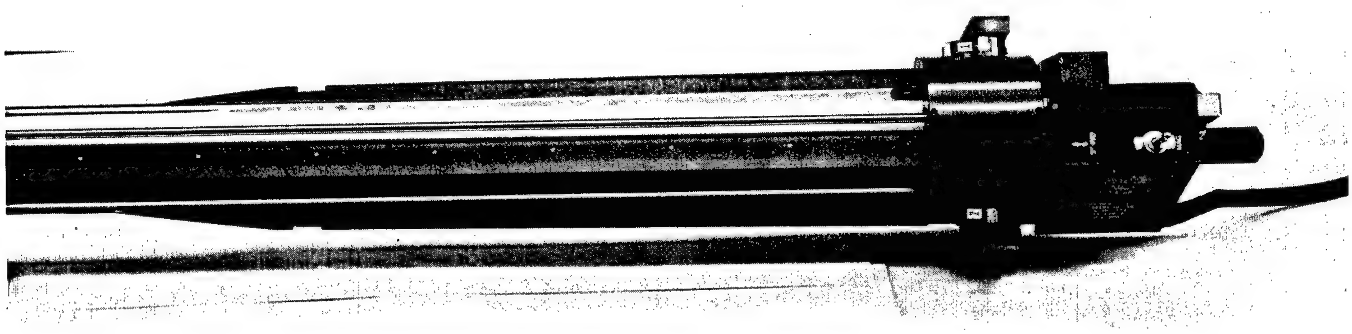


Figure 3

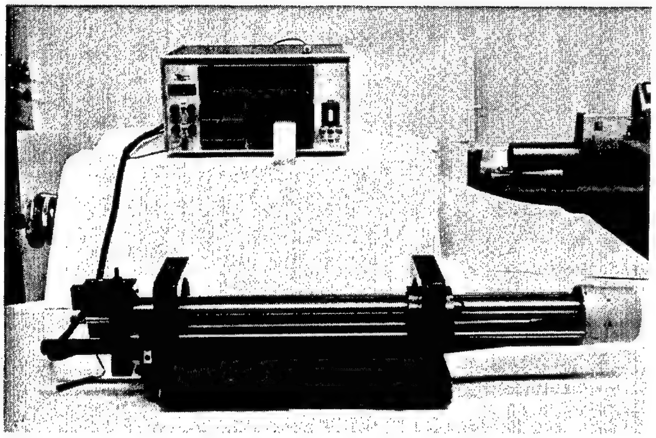


Figure 4

inspected by the Metrology Laboratory Division, PAD, Watervliet Arsenal. The electronic LVDT cartridges and the optical scale also were inspected and found to be acceptable. The gage was reassembled and put into a tube chamber for complete system checkout (Figure 5). The carriage carrying the measurement transducers was moved through the chamber to various points as outlined in an inspection procedure specified by the Arsenal. Measurements were taken of chamber diameters, tapers and location of tapers, datum diameter locations, concentricity of tapered zones, and intersection of conical frustums. This same chamber was also inspected utilizing the present air gage system; results were found to be

Figure 5

compatible. The gaging system was found to be functionally acceptable and all components met drawing requirements and accuracy specifications. Based on the above tests the system was accepted.

The major advantages resulting from use of the new gaging system come from (1) the capability of recording data and (2) the elimination of problems associated with the air gaging cartridges and column readouts. The new system has increased capability over the air gaging system in that the accurate downbore measurement scale allows additional data that can be evaluated at any selected point to determine the actual taper as compared to the nominal taper expressed on the cam template.

System Implemented—Work to Continue

The chamber profile system advanced the inspection capabilities sufficiently so that it has been implemented on the 105mm M68 production line. Quality control personnel are utilizing the gage as per the written inspection procedures for final inspection of the M68 chamber. The printed inspection reports are now included with the other tube inspection data.

As mentioned before, the utilization of a master cam because of the extremely close tolerances that must be maintained increased the expense of the system. Much effort was directed into elimination of the master cam template, but no substitute systems were found that could accomplish the measurements with the required accuracy over the entire range of chamber diameters. All available systems investigated had either insufficient range or accuracy, or would not physically fit into the tube bore. Efforts will continue toward finding a system that can make these required measurements in all types of gun chambers.

One possible solution under consideration utilizes a simpler stepped cam template that reduces the required measurement range of the electronic cartridges as they are moved from the breech face to the bore. However, this system would require an interfaced calculator system to compare the template size with the electronic cartridge's readings at each point to ascertain actual chamber configuration.

As stated previously, upcoming required designs for inspection of the 120mm XM256 cannon chamber will—hopefully—use a system which does not contain a master cam, or at least a cam with a much simplified configuration. As part of the 120mm system, a plotter (with calculator control) may also be incorporated which can plot actual chamber configuration versus nominal.

125 Units/Hour Rate

Auto Assembly of Hybrid IC's Achieved

JAMES F. KELLY is a Project Engineer at the U.S. Army Communications Research and Development Command, where he is involved with production engineering and MM&T programs. During his past five years with CORADCOM and his previous eleven years with ECOM, Mr. Kelley worked on the automation of GaAs diode fabrication, automating the optical inspection of PC boards and hybrid substrates, development of pulsed IMPATT diodes, and the online testing and adjustment of electronic assemblies in addition to many other projects. After receiving his B.S. in Electrical Engineering from Pennsylvania State University in 1953, he pursued graduate studies there and at the City College of New York. He also worked at the Army's Tobyhanna Depot in Pennsylvania until 1964.

Photograph

Unavailable

Mass production of thick film hybrid integrated circuits now makes the widespread use of these devices feasible for military and commercial use. A manufacturing methods and technology project completed by RCA-Burlington for the U.S. Army Electronics Command has developed automated techniques and the necessary equipment for mass producing these circuits. The device selected for technique verification was the CMOS amplifier circuit, a hybrid which consists of a 96 percent alumina substrate onto which are mounted and interconnected nine active (semiconductor) chips, ten capacitor chips, and an impact switch. During the pilot production phase of this project, RCA demonstrated the inherent capability to produce the CMOS amplifier at a production rate of 125 units per hour minimum.

Throughout this project RCA chose equipment for its production run that was available through commercial vendors; no new equipment was developed for this project. Thus, this project was one which brought together various existing manufacturing techniques in order to develop a new system of automated production.

Automated Wire Bonder Evaluated

An automated wire bonder is essential to the development of viable low cost hybrid manufacturing techniques. Due to the sophistication of the technology that is involved in automating the operations of a manual hybrid wire bonder, the bonder itself became the most critical piece of equipment related to this project. When RCA-Burlington began its survey and selection of an automated wire bonder, only two manufacturers supplied such equipment. One of these was GCA, which had 10 to 20 of these units in the field, and another company who had yet to deliver its first equipment. Others who were contacted gave the impression that they were not yet ready to further develop or produce any automated wire bonding machines. For these reasons, the GCA Model 1120 Automatic Hybrid Bonder was chosen as the piece of equipment to be used in this pilot project.

NOTE: This manufacturing technology project that was conducted by RCA-Burlington was funded by the U.S. Army Electronics Command under the overall direction of the U.S. Army Directorate for Manufacturing Technololgy, DARCOM. The CORADCOM Point of Contact for more information is Mr. James Kelly, (201) 532-4996.

There are two basic differences between the Automated Hybrid Wire Bonder and the standard GCA bonder. One difference is that the hybrid bonder contains an additional X-Y table controlled by the Random Access Memory to automatically move the bond head from chip to chip on the hybrid, whereas the standard bonder lacking this feature is capable of wire bonding single IC chips only. The second difference is that the hybrid bonder is equipped with an ultrasonic bonding head and the wire bonding is effected ultrasonically, whereas the standard bonder uses a thermal compression bonding technique which would impose a serious limitation in hybrid processing due to the high temperatures involved.

Wire Bonding Results Prove Promising

There are four factors (all process variables) that critically affect automatic high speed ultrasonic gold wire bonding—(1) the quality and type of wire, (2) chips (device) bonding pad metallization, (3) the substrate bonding pad, and (4) the component configuration design. Assuming that the machine itself is working perfectly, the main process variables are the bonding power level, the dwell time, the substrate temperature, and the quality and type of wire.

The first two variables are unique to each hybrid substrate configuration and are established by a trial and error method until acceptable pull tests are achieved on a continuous basis. While ultrasonic wire bonding can be adequately accomplished on thick film substrates, it is the addition of heat that generally eliminates the marginally adhering bonds.

During the pilot production phase the automatic wire bonding of the CMOS amplifier was demonstrated to have a maximum total cycle time of 87 seconds, which is equivalent to a minimum rate of 41.1 circuits per hour. The projected wire bond miss rate, based on an analysis of the actual wire bond misses, is .05 percent - one out of every 2,000 wires. The average pull strength of a 1 mil diameter gold wire was 8.5 g. This compares to an average for a manual bonder of 7.0 g. This superior pull strength is an important indication of the reliability and consistency that is inherent in the automatic ultrasonic tailless gold wire bonding process.

Substrates Automatically Fabricated

The main emphasis in the area of substrates was on the development, installation, and application of an automated substrate loading and screen printing-drying system; the capacity of existing firing furnaces were deemed adequate for the purposes of this program. Nine manufactures were consulted to see if their products would meet the following requirements. It was felt that a printer should have a production capacity of 1000 prints per hour, a fine line capability of 5 mil lines and 5 mil spacing, the ability to print areas larger than 6 by 6″, and capable of accepting screens from 8 by 8″ to 12 by 12″. After reviewing and analyzing the performance of several models, the final one chosen was AMI's model CP-88. At the same time, the Watkins-Johnson model 8CD-48 was selected as the conveyor drying furnace.

The screen printing process of the CP-88 printer is easily understood, ink is moved across a stenciled screen by a squeegee mechanism (Figure 1). Hydraulic pressure created by the leading edge of the squeegee forces some of the ink through the stencil onto a substrate. The variables in this simple process are numerous. The adjustments (Figure 2) on this printer allow those variables associated with the hardware to be controlled to a great extent, resulting in excellent print definition, repeatability, and deposition uniformity.

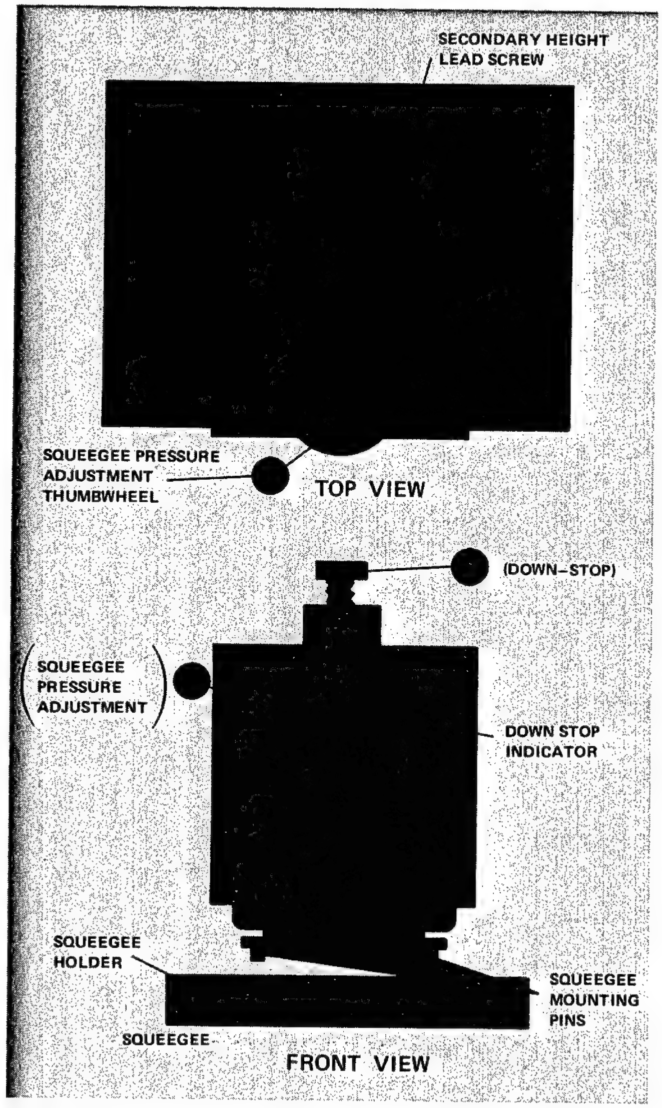


Figure 1

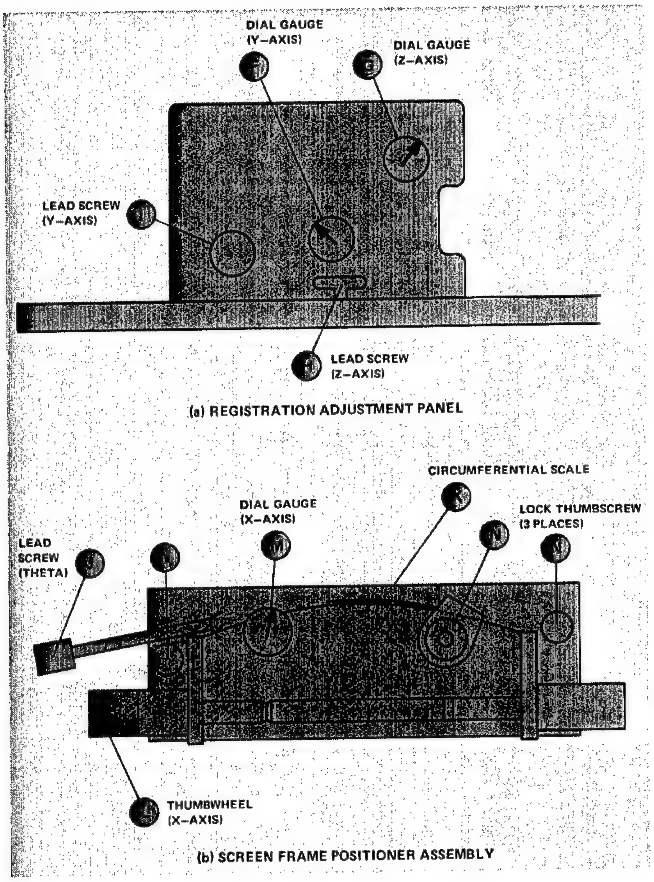


Figure 2

The factor that mainly affected the fabrication rate was substrate waviness. The waviness can best be described qualitatively as a potato chip effect (Figure 3) which makes it difficult to hold the substrates by normal vacuum hold down and snugging methods during the printing process. The resultant ink smearing and jamming of the transport mechanism reduces the printing rate by necessitating frequent machine stoppages for cleanup purposes. Additionally, the waviness affects the quality of printing of the thick film materials, thereby reducing the effective rate of output.

Nonetheless, by the previous manual method the average production printing rate was 150 substrates an hour with 3 operators, whereas by the automated method the production rate increased to 550 substrates an hour with only 2 operators. The total reduction was from 1.2 operator minutes per substrate to 0.22 minutes per substrate.

Automatic Chip Mounting Judged Inadequate

As in other areas of this project, the capacity of existing equipment for implementing all the necessary operations

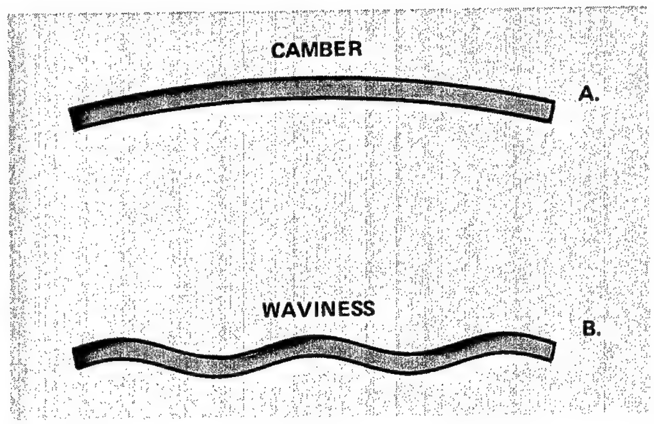


Figure 3

was adequate to meet the initial standards of this program, except for chip attachment. Therefore the main emphasis was on the development of automated techniques and equipment for chip attachment.

A Dixon Model CR-10 Robot component assembly machine was chosen as the production model for this phase of the program. Unfortunately, there were several difficulties in production techniques which were never overcome, making this an unsuccessful portion of the overall program. It was found that the various chip components had to be loaded manually onto the linear vibratory feeder tray. The multichip characteristic of the machine precluded any simple, automated feeding method—it was difficult to impossible to achieve a smooth, steady flow of the chips down the length of the feeder tray.

Yields Analyzed

The overall yield during the pilot production run was 75 percent. It is apparent that the rejection of the remaining 25 percent of the units was caused not by the manufacturing process but by the parametric variations of the semiconductor chips. In particular, the large variation in the threshold voltages of the CMOS chips caused many of the units to be nonfunctional.

It is estimated that the yield could be improved to 90 percent by applying chip probe testing and categorization techniques prior to chip mounting. In conjunction with this, the resistor networks that established the threshold biasing conditions for the circuit would be adjusted on a batch basis to accommodate the various chip categories.

Having met all the objectives of this program, a follow-up effort will be implemented for the integration of the various elements that would constitute a continuous automated production line and that would be available for the mass production of military hybrid circuit units.

Proximity Fuzes Tested On-Line

New Technique Measures Oscillator Sensitivity

NEIL D. WILKIN is an Electrical Engineer with the U.S. Army Electronics Research and Development Command, Harry Diamond Laboratories, in Adelphi, Maryland, where his most recent activities have been in the field of Transient Radiation Effects on large scale integrated circuits. Prior to that, he was assigned to the Radio Systems Branch, where this sensitivity measurement work was performed. Mr. Wilkin also has worked in the area of radar security for military installations. He received his B.S. in Physics from Western Michigan University and since has taken numerous graduate level electrical engineering courses at the University of Maryland.

Production line fuze testing now can be performed in a small anechoic chamber using the oscillator sensitivity measurement technique, following a manufacturing technology project conducted by the Harry Diamond Laboratories of the U.S. Army Materiel Development and Readiness Command. The small chambers are employed to measure and compute errors.

Pole Test Limited

The standard measurement procedure for determining oscillator sensitivity of radio proximity fuzes historically has been the pole test. The fuze under test was moved either toward or away from a large reflecting screen while the detector voltage was monitored. Generally, the apparatus for moving the fuze consisted of a pole and a hoist; thus, the procedure became known as a "pole test". Little was known about its accuracy, except that intuitively it seems to simulate the "actual use" situation. Errors such as those due to finite screen size and the effects of reflections from the pole and hoist apparatus were ignored or considered minimal. A long standing clue that these errors may be significant has been the difference in test results when the same fuzes were measured on different pole test facilities. Measurements varying as much as 2 to 1 have been obtained in extreme cases. Two other problems with the outdoor pole testing are the lack of security for the system under test, and the limitation on the test to days of fair weather.

As a companion to the pole test, small loading and unloading chambers have been used for laboratory or production line testing. These chambers employed either mechanically rotating or electronically switched dipoles to induce a reflecting signal into the oscillator. The chambers are calibrated over a frequency range by direct comparison with the pole test.

This mantech effort covered an improved technique for sensitivity measurement employing a small anechoic chamber in which the errors can be computed or measured. It is the same technique as described in an earlier

NOTE: This manufacturing technology project that was conducted by Harry Diamond Laboratories was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The HDL Point of Contact for more information is Mr. Neil D. Wilkin, (202)394-3070.

report which covered measurements made in a large anechoic chamber.[1]

The fuze under test is fixed in a small anechoic chamber. Sensitivity is determined by first measuring the fuze radiated power and then, after accounting for all losses in the system, "playing back" a signal to the fuze in a magnitude which simulates a given height above an infinite plane reflector at a prescribed reflection coefficient. The fuze detector's response to this signal is recorded as a measure of fuze sensitivity.

Four areas were studied during this project:

- Refinements to the basic test technique
- Standard loop antenna fabrication and calibration
- Characteristics of the small anechoic chamber
- System errors.

Each area is covered in a separate section in this article.

Basic Method Used

The absolute measurement procedure is outlined below; however, a shortened procedure is described later.

The fuze oscillator detector under test is placed at one end of an anechoic chamber, preferably at the end with the largest quiet zone. At the opposite end, an antenna, A_3, is placed so that a portion of the oscillator signal can be received and measured and a processed signal can be returned to the oscillator (Figure 1). An additional antenna is used to sample the oscillator signal—this sample to be used as the input signal to the signal processor. The signal processor is a frequency offset generator (single sideband technique) which varies the phase and then amplifies the signal for return via A_3 to the oscillator. In an alternative procedure, the signal processor is replaced with a standard signal generator and the oscillator is allowed to "lock in" to the generator frequency. The lock-in response of the oscillator is recorded as the generator frequency is varied. This latter method can be applied only to unmodulated oscillator systems. The magnitude of the processed signal is set so that the oscillator is presented with a field equal to a value corresponding to a desired height above an infinite perfect reflector. This desired field strength is the result of the forward power, P_f, from the processor; the relationship between this power and the field can be determined as follows.

We may start by defining the space loss, L_s, as the ratio of the available return signal power*, P, at the oscillator to the power P_{A3}, which is the net power delivered to the terminals of antenna A_3 (Figure 1). For reciprocal transmission, this space loss holds for the test setup shown in Figure 2. Thus, we can also write the space loss as the ratio of the available power, P_{D3}, to the power, P_1, radiated by the antenna, A_1, of the oscillator. Hence,

$$L_s = \frac{P}{P_{A3}} = \frac{P_{D3}}{P_1} \quad . \qquad (1)$$

When the oscillator is turned on, the power, P_3, is mea-

[1]Neil D. Wilkin, "An Absolute Measurement Procedure to Determine Oscillator-Detector Sensitivity and Power," Harry Diamond Laboratories, HDL-TR-1606 (April, 1972).

*The available power, P, is equal to the return signal power density at the fuze multiplied by the receiving cross section of the oscillator antenna.

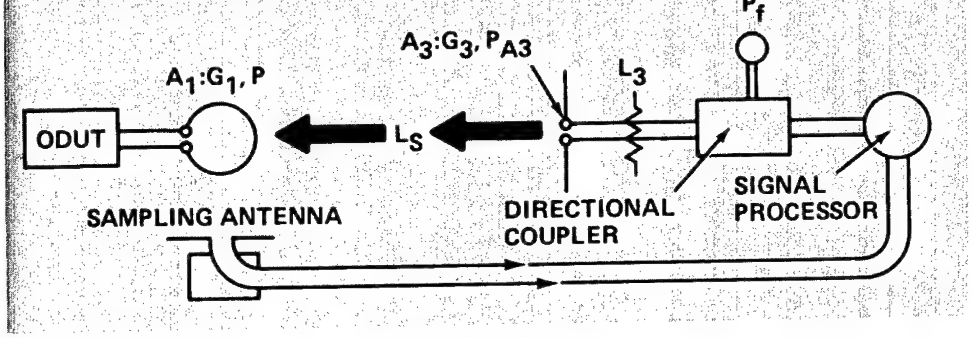


Figure 1

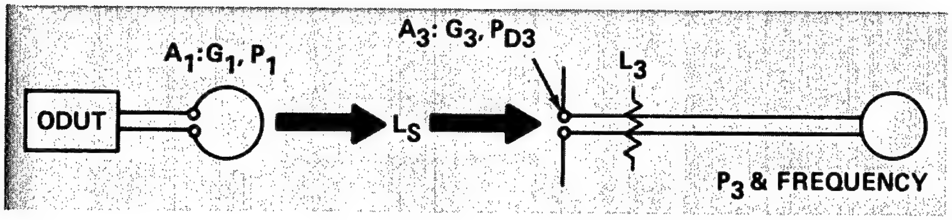


Figure 2

sured (Figure 2). Then the oscillator is removed from the chamber and replaced with a standard antenna, A_2, in the same physical location. The absolute gain of antenna A_2 must be known. The oscillator frequency and the power P_3 then can be duplicated by adjustment of the signal generator shown in Figure 3. Thus, we may equate the power gain products:

$$P_1G_1 = P_2G_2 \quad . \qquad (2)$$

G_1 and G_2 are the power gains for antennas A_1 and A_2, respectively. P_2 is the net power radiated by antenna A_2, or

$$P_2 = L_2P_{for} - P_{rev}/L_2 \quad . \qquad (3)$$

P_{for} and P_{rev} are the forward and reverse power, respectively, in the transmission line, as measured through the directional coupler. L_2 is the match line loss of the coaxial cable. P_{D3} can be related to P_3 by the following equation:

$$P_3 = P_{D3}L_3(1 - Z^2) \qquad (4)$$

which includes the antenna mismatch parameter, Z^2, and the transmission line loss, L_3. The power meter used here is assumed to be well matched to the line. L_s can now be calculated by combining equations (1) through (4):

$$L_3 = \frac{P_{D3}}{P_1} = \frac{G_1P_3}{L_3G_2P_2(1 - Z^2)} \quad . \qquad (5)$$

To simulate a particular height above ground, $P_{A3}L_s$ is set equal to P_1L_h, where L_h is the two way transmission loss between antenna A_1 and an infinite reflector with a reflection coefficient of unity. Thus,

$$L_h = \left(\frac{G_1C}{8\pi hf}\right)^2 \quad . \qquad (6)$$

C is the speed of light in free space, h is the height to be simulated, and f is the operating frequency. P_{A3} is related to P_f (Figure 1) by

$$P_{A3} = P_fL_3(1 - Z^2) \quad , \qquad (7)$$

where P_f is the forward return signal power at the directional coupler.

Forming $P_{A3}L_s = P_1L_h$ from the equations above and

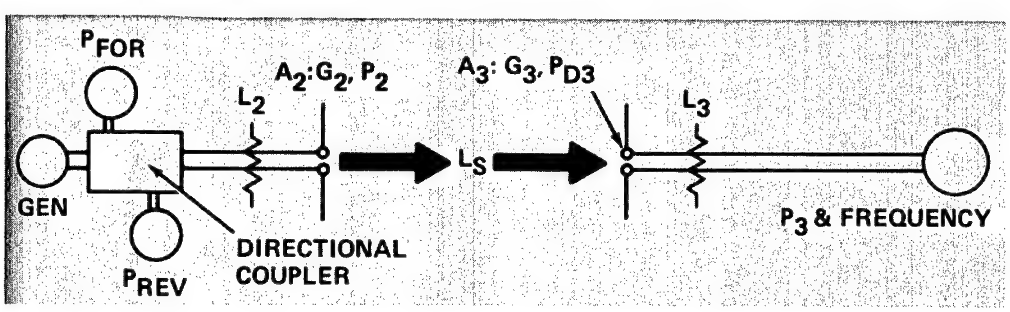


Figure 3

then solving for P_f, we arrive at the desired result:

$$P_f = \frac{P_2^2}{P_3} \, \frac{G_2C}{8\pi hf}^{\,2} \quad . \qquad (8)$$

Thus, Equation (8) gives the power P_f necessary to make the magnitude of the return signal identical to that for an oscillator suspended at a height h above an infinite reflector.

One needs only to vary the return signal phase to determine the detector response after the magnitude of P_f has been set. If the phase is varied through 360 degrees, the resultant peak-to-peak detector voltage swing is equal to the magnitude of the Doppler envelope at height h. One should note that the oscillator antenna gain, G_1, the mismatch losses $(1 - Z^2)$ of antenna A_3, and the loss L_3 in the cable connecting A_3 to the power meter do not enter the equation. Of prime importance, however, is the standard antenna gain, G_2. The accuracy of the measurements depends on how well this is known.

On occasion, the laboratory equipment may not provide sufficient return signal power to simulate a given height above the reflector. Since the detector voltage is directly proportional to the square root of the return signal power, one can set the return signal magnitude to any convenient value and calculate the detector response for the desired height h. The radiated power of the oscillator can also be calculated.

The basic method can be shortened by precalibrating the anechoic chamber and plotting all factors for losses and other corrections together versus frequency. This shortened method can be applied to any chamber and is still an absolute measurement: the calibration technique is based on standard measurements and does not need to be checked against any other type of sensitivity measurement system.

Standard Antenna (A_2) Considerations

To insure accuracy of measurements using this technique, care must be exercised in the selection of the standard antenna, A_2, particularly when the measurements are performed in a small anechoic chamber. Greater accuracy is obtained when a standard antenna is of the same type as that of the fuze (for example, a loop standard for a loop fuze). Use of a dipole standard when measuring a loop antenna fuze may introduce errors in the estimate of chamber attenuation, because different reflecting paths come into play when the antennas are of the same polarization and radiation pattern. The problem is generally more acute when a small anechoic chamber is used because of the greater importance of reflecting paths. On the other hand, if the measurements were made in free space, the type of standard antenna would be unimportant so long as the absolute gain were known.

Standard dipole antennas are readily available, but standard loop antennas with 50 ohm drive impedance and known gain characterizations are unavailable commercially. As a result, HDL has designed and fabricated a unique loop antenna for use as a standard. Each antenna has a bandwidth of approximately 35 MHz. Two sets of four antennas were fabricated, the second set serving as a spare. Further, each loop antenna is designed to have a 50 ohm radiation resistance which is determined by its diameter.

Eight equally spaced capacitors are inserted in series with the loop. These capacitors both tune the loop to resonance and insure uniform current around the loop. The antenna could be fed across any of these capacitors, but since an unbalanced feed line is desired, a different technique is used.

A balanced loop can be bisected by a ground plane without the loop characteristics being upset. Each half of the loop can be driven from an unbalanced line from within the ground plane in such a manner as to produce an in-phase current around the loop. Under these conditions, each feed point impedance is 25 ohms. By use of quarter wave matching sections of 50 ohm characteristic impedance, each feed point impedance can be transformed to 100 ohms and these terminals connected in parallel, making a 50 ohm feed point for the system as shown in Figure 4. The location of the unbalanced feed point is along the axis of the loop—hence, in the null of the antenna radiation pattern. Some residual electrical imbalance will still exist because of capacitive currents from the high side of each feed point back to the ground plane. By extending the ground plane symmetrically for some distance in the direction away from the feed, this imbalance is minimized. Figure 5 shows one of these standard antennas.

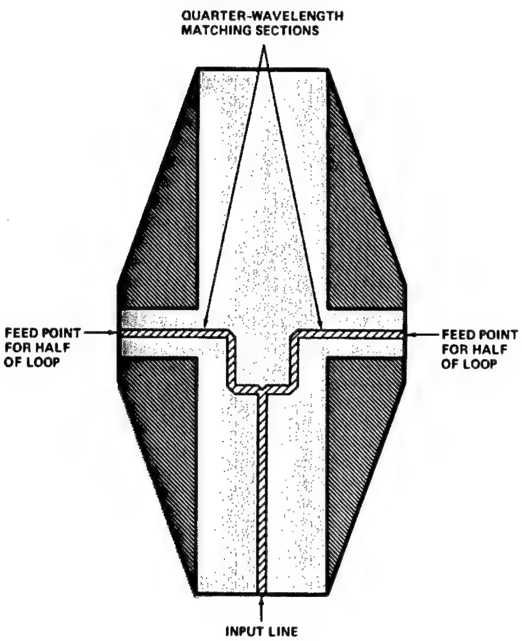


Figure 4

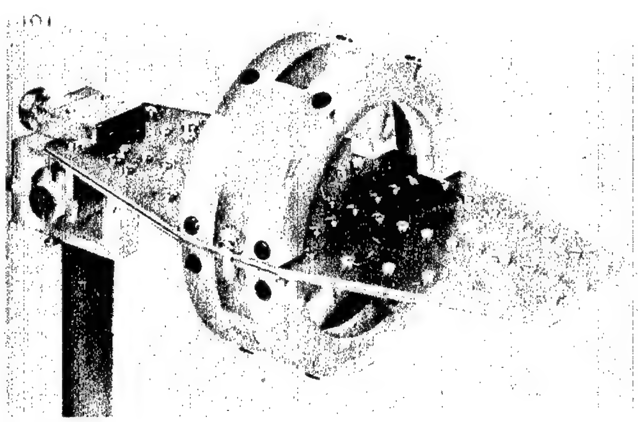


Figure 5

Small Anechoic Chamber Measurement

The simple chamber studied in this problem is shown in Figure 6. The chamber is assembled with 12 sheets of 10 × 61 × 61 cm flat absorbing material. The sheets are supported by an external plywood structure not shown in the figure. One sheet near the test location is removable so that the fuze under test can be easily changed. Access ports are provided to mount the test antenna in the locations shown in Figure 7. The test antennas are fixed in place and need no adjustment. The fixed position for the fuze under test is designed so that the standard antenna can be placed in the same location when necessary.

The small chamber used in this test was not RF shielded, but shielding is desirable when the chamber is surrounded by strong external fields. The shielding further isolates the fuze under test from external influence.

Error Analysis

The accuracy of the sensitivity measurement can be estimated—it was found that the sources of errors can be divided into three categories: antenna location and placement errors, metering equipment errors, and meter reading errors. Meter reading errors can be minimized by patience and care, and certain metering equipment errors will tend to cancel.

A sample of 40 fuzes was tested three different ways: by a pole test (at what is considered to be the best available pole test facility), in a large anechoic chamber (7.62 × 7.62 × 15.24 m), and in the small anechoic chamber described earlier in this article. In each of the three facilities, two sets of sensitivity measurements were performed on each fuze. In the case of the pole test, all 40 fuzes were measured once, and then the same 40 fuzes were retested on the same facility.

For the chamber measurements the test equipment was set up and a calibration curve [1/L(f) versus frequency] was obtained. The sensitivity of the 40 fuzes was then measured. Antenna positions and fuze locations were noted, and the test setup was dismantled and then reset up for a second test. No new calibration curve was run, however. An error may, thus, be introduced by not using the same mean distance between A_3 and the fuzes under test. Several other sources of error are possible (for example

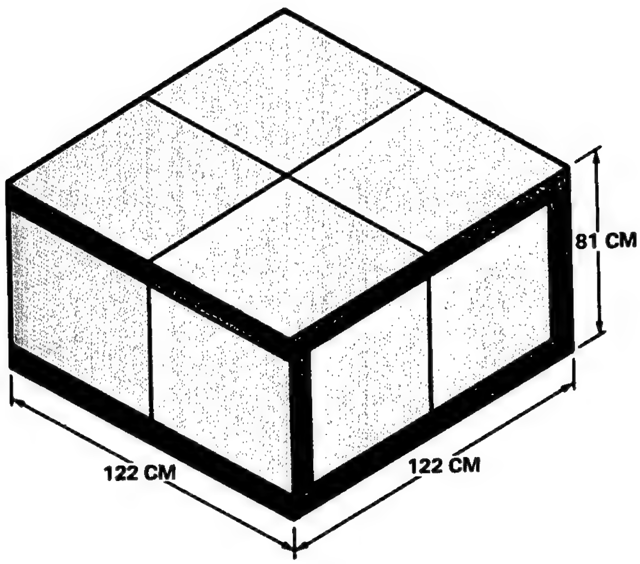


Figure 6

temperature effects and fuze power supply variations), but care was taken to minimize variations in these quantities.

All sensitivity data calculated for the chamber tests used the same fixed value of antenna gain, 1.22, regardless of frequency. The estimated accuracy with which the gain was known at the various frequencies did not seem to justify using a different gain for each frequency. Since the antenna gain varies over any given antenna bandwidth and the antenna gain was included while the 1/L(f) plots were obtained, a smoothed curve was used in the sensitivity calculations along with the constant antenna gain value of 1.22.

In the case of the small chamber, the random errors can be estimated. Typically, the attenuation varies about 0.16 dB/cm for either transverse, lateral, or vertical displacements of the fuze from the calibration position. The estimated transverse and lateral displacement error is on the order of 0.635 cm each. Possible vertical displacement is on the order of 0.254 cm. The estimated rms error due to these factors alone is 3.5 percent.

The remaining random errors occur in measuring P_3, P_f, and the measured detector voltage. Assuming that meter reading errors on the order of 1 percent are typical, then the rms error contributed by reading these quantities is 1.2 percent. The total random error is then 3.8 percent.

The remaining errors in the equation involve two parameters, the previously determined errors and the antenna A_2 gain, G_2. The largest single error is associated with the measurement of this antenna gain. The antenna gain error was determined by the National Bureau of Standards during the gain measurements that they performed. Using the NBS quadrature sum error of 0.097 for the antenna gain and 0.038 from the previous analysis, an overall estimated error of 0.104 or 10.4 percent is obtained.

Further Conclusions

In addition to the primary conclusion stated at the beginning of this article, it was found that a desirable feature of any chamber employed for this sensitivity measuring technique is shielding from external fields. The shielding is accomplished by constructing the chamber wall with one or two layers of a continuous metal surface.

The calculated overall system error for the equipment used in this study of the small anechoic chamber measuring system is 10.4 percent. Careful relative positioning of the fuze and antenna A_2 and the location of antenna A_3 is important in reducing measurement error. This was illustrated by the correlation tests run for small chamber versus small chamber data and the large chamber versus large chamber data where the test equipment is torn down between tests.

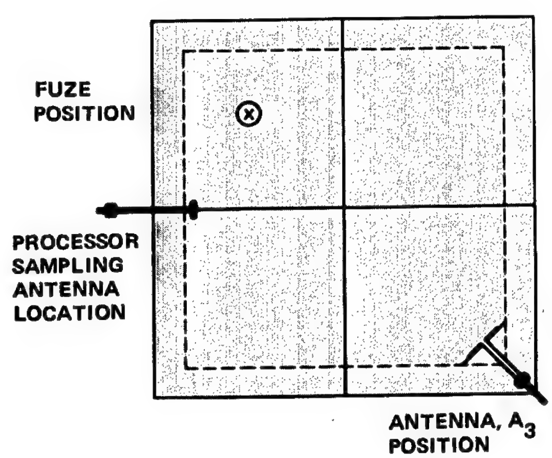
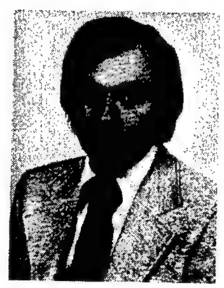


Figure 7

Implementation Primary Emphasis

Five Task Program Sets New Tone

RICHARD A. KOTLER is Manager, Manufacturing Technology, Engineering Directorate of the U.S. Army Missile Command. After joining MICOM following his graduation in 1967 from Tennessee Technological University in Industrial Engineering, he has held continually more responsible positions in numerical control and computer aided manufacturing programs, printed circuits, and hybrid microcircuits; he is a member of the International Society for Hybrid Microcircuits. He received his MBA from Vanderbilt in 1978, and now serves as Coordinator of MICOM Manufacturing Methods and Technology programs.



Early implementation of new findings through rapid, concurrent dissemination of information to manufacturers of electromagnetic components received top emphasis during a two year U. S. Army manufacturing technology project. A major attack on the main limitation of rapid production—lengthy cure times of encapsulating resins—produced 5 most applicable types for further study from over 40 compounds.

The purpose of this two year MM&T (Manufacturing Methods and Technology) Program was to investigate, evaluate, and implement techniques for the manufacture of low cost, highly reliable electromagnetic components for missile systems applications. This program was conducted by Hughes Aircraft Company under sponsorship of the U. S. Army Missile Command. The emphasis of this program was on implementation, through a continuing program which disseminated the findings from the work to electromagnetic component manufacturers.

The program was conducted in two phases. Phase I was concerned with improving the manufacturing methods of potting/encapsulating electromagnetic devices as well as investigating winding techniques. Phase II concentrated on interconnection techniques, tooling, and structural parts. The combined results of these five tasks implement improved manufacturing methods for electromagnetic components so that a significant payback in manufacture and life cycle costs of present and future missile systems are obtained, due to lower production costs, higher process yield, and improved reliability.

NOTE: This manufacturing technology project that was conducted by Hughes Aircraft Company was funded by the U. S. Army Missile Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Mr. Bobby Austin, (205) 876-3604.

Low Stress Potting/Encapsulation Resins Needed

A large number of materials are available and more are being developed for the encapsulation/potting of magnetic components. A series of tests for evaluating 36 parameters and properties of these materials was established, as no such standardized conditions existed. These conditions consisted of such diverse standards as voltage, temperature, frequency, sample size, and configuration.

A total of 40 embedment materials were tested and evaluated for high reliability magnetics, providing a representative cross section of the available material types. Only 20 of the 40 materials were evaluated on the basis of outgassing because of either a lack of manufacturers' data on the remainder or the equivalent Hughes specification.

Pressure sensitive magnetic cores and other fragile electronic components require low stress potting/encapsulation techniques and materials. Quantitative measurements of stress as a function of temperature were determined in several tests, but more work on the testing devices themselves is needed. Concurrently with the development of those pressure sensitive inductors was the observation of quantitative effects of high hydrostatic pressures on the electrical parameters of small toroidal inductors themselves. Ferrites, MPP, and tape wound cores were exposed to a pressure of 10,000 psi with surprisingly small effects. Subsequent tests showed that unbalanced rather than isotropic stresses significantly alter the magnetic properties.

Five Resins Acceptable

A typical high voltage TWT saturable core transformer design (Figure 1) was used as a test compound for five selected encapsulation materials. No one resin proved to be universally ideal encapsulation material. Tradeoffs of parameters and properties are required for each application. These five materials were judged to have the most acceptable combination of parameters, including compressive stresses of less than 200 psi at the lowest temperatures: Epon 825 with HV hardener; Scotchcast 255; Eccoseal 1218; Hysol C-60; and Hysol C15-015. As an example of tradeoffs only, the Epon 825/HV was corona free during high voltage tests; the other four had varying degrees of corona present. On the other hand, for low voltage applications under a 250 V peak, some of the others had more optimum parameters.

A major source of failure in encapsulated magnetic components wound with fine wire is breakage of the leads between the coil and the terminals caused by thermal expansion of the resin. It was determined that to prevent this effect intermediate leads of AWG 36 or larger should always be used.

Current Winding Techniques Inadequate

Based on the results of this investigation and visits to the vendors, it is recommended that all reels of magnet wire intended for high reliability magnetics be shipped, stored, and handled to protect the wire and its reel from damage and contamination. The best protection is one in which there is a paper wrap around the wire, and in which the reel is encased in rigid foam and further covered with a plastic bag.

Shuttle type toroidal winders should be modified to allow the use of an electrical short detector (Figure 2) placed between the shuttle ring and the wire being wound on the toroidal core. This serves the dual purpose of detecting insulation damage during winding or faulty insulation on the wire itself.

Furthermore, the usual QA practice of approving a reel of wire for high reliability applications by inspection and analysis of a few feet taken from the beginning of

Figure 1

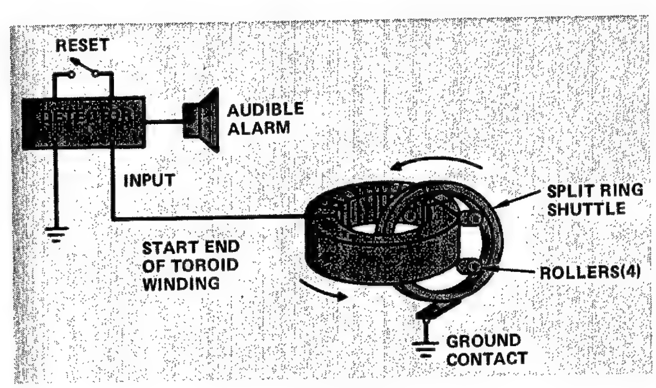


Figure 2

the reel is not considered adequate. Equipment capable of continuously monitoring the insulation integrity of the wire during the winding operation is recommended. This can be easily done for shuttle type toroidal winders as noted below; other types of winders will require some development effort.

Finally, insulation and even conductor deformation may occur when fine wire is wound at rated tension on square bobbins, due to the stress buildup at the corners. It is recommended that round rather than square bobbins be used; otherwise, some wire damage may occur in the winding operation.

New Interconnection Techniques Defined

Investigations of wire stripping techniques—including heat, abrasive, air abrasive, laser, and chemical—showed that no method of removing insulation from magnet wire has a clear cut advantage over the others. This was especially true when the wire in question was either of fine/ultrafine guages or of high temperature polyimide (ml) materials. Insulation removal with a CO2 laser showed promise with the larger wire sizes, but further work is required for application to fine wire guages. Removal of insulation by abrasive particles driven by air blast, two variations of which are shown in Figure 3, was also effective for the larger wire sizes. Further work needs to be done, however, to find a nozzle design and an abrasive material which will yield clean, solderable surfaces.

Wire sizes smaller than AWG 36 should be joined to intermediate leads AWG 36 or larger, then taped or anchored to the winding so that the intermediate lead interfaces with terminals for connection to outside components. It was found that wire sizes of less than AWG 36 should not be routed through encapsulation materials for any great distance, because thermal expansion of the material can cause breakage.

During the encapsulation of high voltage transformer windings, extensive care is taken to prevent the occurrence of voids—which are a source of corona, causing progressive degradation of the insulation material. It is also considered imperative to eliminate any sharp points which may occur in the high voltage gradient regions. What has not been appreciated previously is that a sharp point in the high voltage winding can have a high enough voltage gradient to actually create voids in insulation where none originally existed. Once this void is created, the insulation begins to fail progressively. It was discovered that by using diagonal cutters or scissors in cutting fine wire, the resultant sharpness of the cut increases the voltage gradient into the region where voids can be generated with only a moderate amount of high voltage applied to the winding. Caution must be taken, especially, in the termination of fine wire to the intermediate lead wire interface. A method of solder balling or putting a conductive sphere over the joint to control the gradient was also investigated.

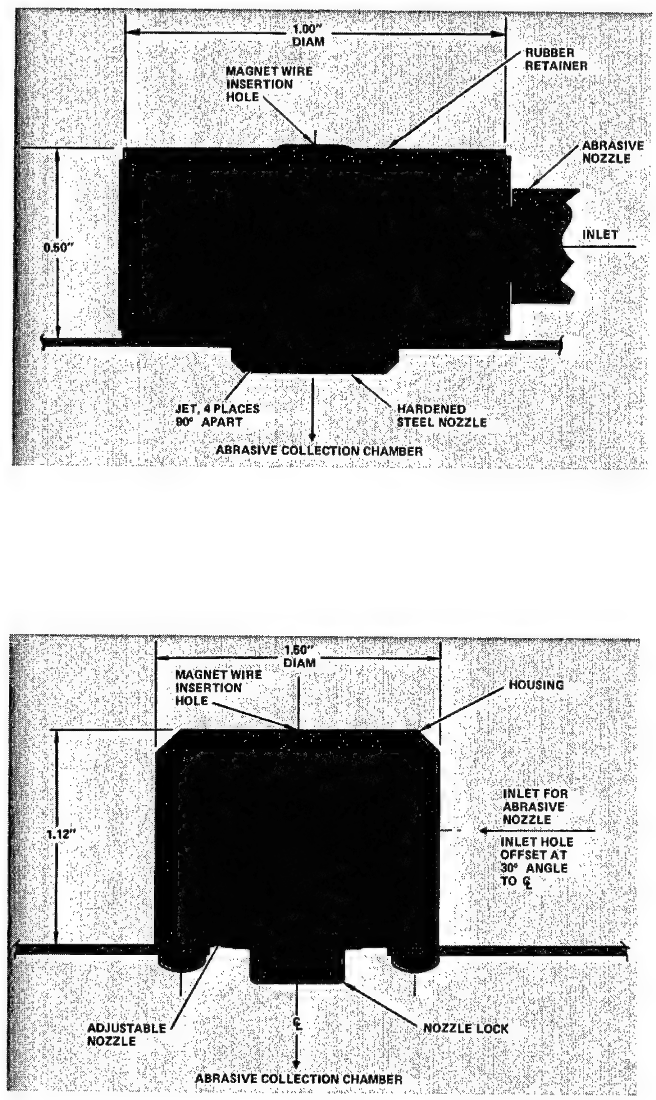


Figure 3

Tooling Review Sheds Light

A fourth area of investigation in this project was the review of both current and proposed tooling and equipment used for the encapsulation and potting process. Individual molds—designed as a pressure vessel up to 500 psi—can accommodate both pouring in vacuum and cure of the encapsulant under pressure for low production quantities. Slush molds and molds fabricated from RTV silicone rubber can be used for low production quantities if they are poured in a vacuum chamber and cured in a

pressure vessel at 500 psi. Liquid injection molding (LIM) techniques are yet another approach which shows promise for large production quantities—with proper mold design and selection of materials.

As an alternative to the pressure vessel mentioned above, the silicone molds after pouring in a vacuum may be centrifuged for 5 to 10 minutes to remove the trapped air, then cured in an oven. Use of the centrifuge appeared to give an equally void free encapsulation of low voltage components—the CIV for high voltage components was higher for the pressure cured samples than the centrifuged ones.

Four Structural Factors Determined

It was found that an electrostatic shield sprayed on a bobbin surface after molding was completed enabled a better process control with less problems than if an integral shield was positioned in the mold cavity prior to the molding. Moreover, it was discovered that a high resistance coating for bobbin shields can be employed without requiring any sort of gap, which is necessary for low resistance materials because of the shorted turn effect.

High temperature thermoplastic bobbin materials were not considered acceptable for high reliability components because of brittleness, along with softening of the region around the swaged or bonded terminals during soldering.

Anchoring of wires during winding operations with quickset adhesive was found to be superior to mylar tape, as a void free encapsulation is guaranteed.

Finally, it was found that welding rather than soldering straps during C-core banding operations eliminates solder creep problems. A diagram of this process is shown in Figure 4.

Implementation Under Way

The implementation requirements included dissemination of information on an "as you go" basis during the contract period, rather than waiting for completion of the MM&T program. In this manner, it was hoped that information could be put to use sooner in the manufacture of high reliability missile magnetic components. Although the MM&T program is expressly for the manufacturing operation, some of the information uncovered to improve reliability applies to the design phase; these items will be passed along as well. The implementation phase comprised both Hughes' inhouse operations as well as that of outside vendors; presentation of three papers at technical seminars; and a government/industry debriefing.

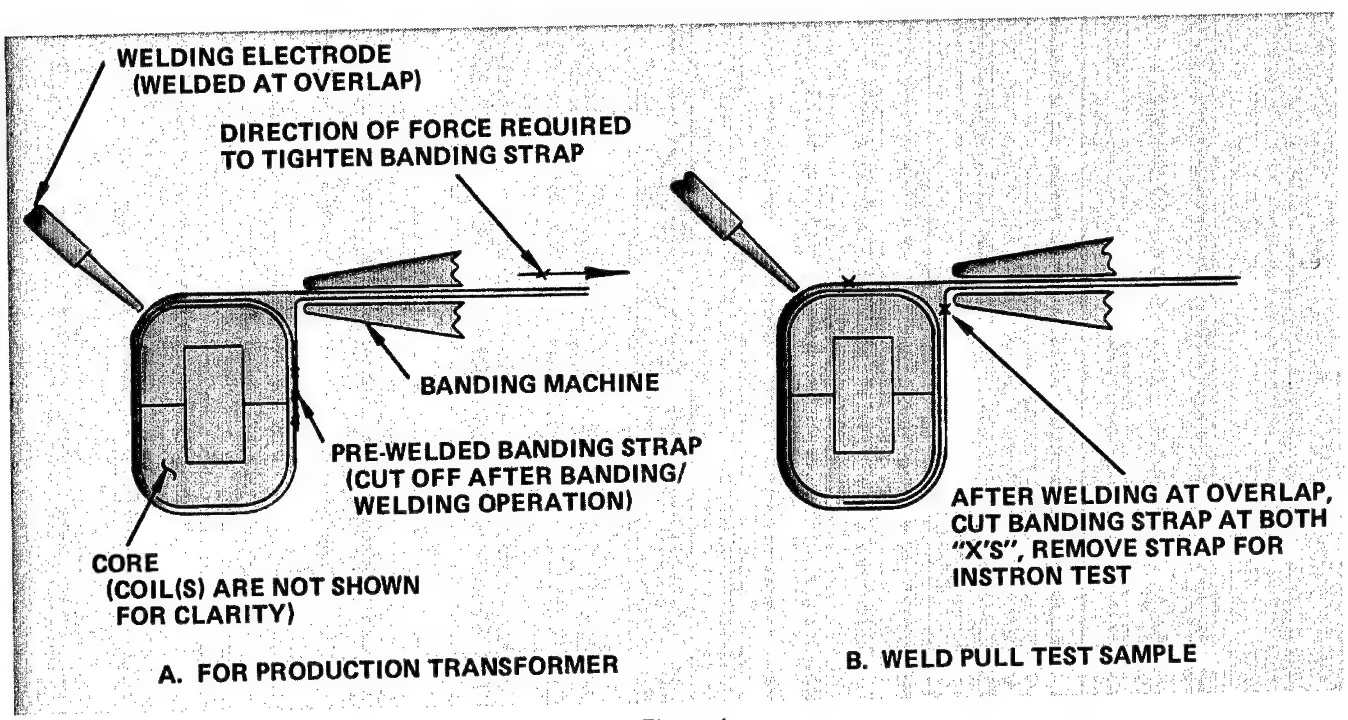


Figure 4

Brief Status Reports

Project 1905. PBX Continuous Casting for Munitions Loading. The added use of castable plastic bonded explosives will create production shortfalls. Most PBX cannot be used in present melt/cast equipment. PBX production is now done at two Navy plants which could not handle loading of castable PBX in bombs. This project will establish high production rate continuous processes for mix and cast of various PBX formulations; also it will identify and evaluate equipment and processes, select and test equipment, and integrate acceptable items into an operating PBX processing pilot plant. Processes on four explosive systems were baselined for an economic analysis to design a continuous PBX pilot plant. Plant layouts, equipment listings, and a preliminary hazards analysis have been completed. For additional information, contact J. Zehmer, NAVAL WEAPONS STA., Autovon 953-4764.

Project 4392. Joining Dissimilar Metals. Current armor designs employ only one type of metal for welding. Bi-metal inserts will be investigated, and combination mechanical and weld joints will also be studied. Procedures for welding transition materials were applied to full sized ballistic test samples. Test specimens have been sent to Aberdeen for ballistic firing to determine joint integrity. For additional information, contact B. Schevo, TACOM, (313) 574-5814.

Project 4568. Technical Data/Configuration Management System. There currently is no technical data/configuration management system. This project will develop a DARCOM wide standard technical data/configuration management system and improved technical data packages. A scope of work has been prepared and is being negotiated with Rockwell, Inc. The investigation of the possibilities of utilizing microwave has been deleted from the project since it is felt that sufficient data channels can be obtained by other means. Computer programs were prepared and tested. Government personnel were trained for implementation of the new system. For additional information, contact D. Johnson, MICOM, (205) 876-1880.

Project 1075. Electronics Computer Aided Manufacturing (ECAM). Although integrated circuits, hybrid circuits, printed circuits, and cables are designed on a computer, there is little computerized control of processes used to produce these items. A master plan is needed to define the area and requirements. This project will develop a DoD master plan for computer aided design and manufacture or electronic systems. Air Force's ICAM and NASA's IPAD programs were used to define CAD/CAM and electronic technologies to make integrated circuits, hybrid circuits, printed circuits, and cables. For additional information, contact G. Little, MICOM, (205) 876-3848.

Project 8192. Turbine Engine Productivity Improvement. The Stratford Army Engine Plant (SAEP) was in need of modernization. Both the plant and nearly 50 percent of the equipment were over 25 years old. A combination of aging manufacturing facilities, methods, processes, etc., resulted in excessive manufacturing costs. The thrust of this project is to analyze the entire SAEP facility with a focus on productivity, cost savings, and plant modernization. Areas to be evaluated include both management and business systems, manufacturing methods, processes, equipment, and facilities. For additional information, contact Jim Corwin, TSARCOM, (314) 263-2220.

Project 5024. Gear Die Design and Manufacturing Utilizing Computer Technology (CAM). The control of dimensional tolerances of forged bevel gears presents a unique problem since these gears are not manufactured to theoretical equations. The bevel gear is not defined dimensionally but is presented as requirements for tooth bearing patterns. This program will eliminate the current trial and error methods by utilizing CADCAM methods and interactive graphics techniques. Excessive scrap, unexpected die wear and breakage, and the high cost of forging dies will be addressed. A set of computer programs has been developed to define the exact tooth form of a hypoid or spiral bevel gear or pinion. The finite element programs for stress analysis and temperature distribution of the die have been completed. Elastic die deflections and bulk shrinkage due to temperature differentials have been calculated. For additional information, contact T. Wassel, TACOM (313) 574-5814.

Project 5045. Spall Suppressive Armor for Combat Vehicles. Current metallic armor does not suppress flying shrapnel within the vehicle

crew compartment. This project will establish methods of applying spall suppressive armor to the interior walls of combat vehicles. Methods of attaching Kevlar spall liner material to the interior of a combat vehicle were developed. All three armor liner kits have been manufactured. For additional information, contact A. Fisher, TACOM, (313) 574-5200.

Project 5062. Production of Armored Vehicle Vision Blocks. At the present time there is a need to fabricate an economically improved ballistic vision device. This project will establish methods for sandwiching high light index materials in production. TACOM made a fixture for ballistically testing glass/plastic vision blocks. Tests were made by AMMRC and showed composite windows to be superior to heavier and bulkier all glass blocks. For additional information, contact C. Houston, TACOM, (313) 574-5814.

Project 6035. Establish On-Line Nondestructive Testing for Tracked Combat Vehicles. Extensive in-process nondestructive test of many XM-1 components will be essential during production to ensure compliance with designated quality control requirements. This project will provide a nondestructive quality assurance test system to be adapted to an on-line production operation. The ability to accurately determine types of linear discontinuities with a-scan techniques is operator dependent and time consuming. Data recognition and pattern recognition analysis has been initiated using a microprocessor based production system. For additional information, contact E. Nader, TACOM, Lima Army Ctr., (313) 574-6347.

Project 6038. High Deposition Welding Processes for armor. Welding is labor intensive and high cost. It is a major cost driver in armor vehicle manufacture. High deposition welding processes will permit welding to be accomplished more rapidly, thus reducing manpower requirements and increasing productivity. The electrodes were selected, and process planning for cruciform tests was completed. The purchase requisitions have been submitted for the equipment. For additional information, contact B. Schevo, TACOM, (313) 574-5814.

Project 6054. Advanced Metrology Systems Integration. The metrology methods used in military vehicle manufacture in general employ contact gauges, manually operated. This represents a substantial part of the cost of our military vehicles. Non contact in-process gauging (electro-optical and laser) will be adapted to a vehicle machining operation. Solid photography will be adapted to meet the measuring requirements of components such as turbine blades. For additional information, contact B. Roopchand, TACOM, (313) 574-5814.

Project 5064. Lightweight Saddle Tank. The project was developed to fabricate an economical high impact nonmetallic fuel tank. It will establish procedures and methods to produce a leak proof fuel tank. A five ton fuel tank trial installation was completed at TECOM test sites. There was some leakage in fittings and the tanks distorted due to lack of ribs and heavy weight when filled. However, they are still serviceable with no leaks if bonded. For additional information, contact D. McClendon, TACOM, (313) 574-6491.

Project 5067. Plastic Battery Box. Metallic battery boxes are subject to corrosion, thereby damaging the vehicle. This project will establish production techniques to use non-corrosive nonmetals. The hardware was shipped for mold pattern tooling. Battery box units were fabricated and tested by the contractor. Hardware was made and delivered to TACOM. Weight reductions of 41 to 50% were obtained. For additional information, contact S. Allen, TACOM, (313) 574-6712.

Project 5083. Upscaling of Advanced Powder Metallurgy Processes. Powder metal processes have not been utilized in large components. This project will establish processes which produce high density, high strength, large complex shapes. The CAD program modification for the design of the preform is under way. The die set was completed and assembled into the 700 ton press. Forging tests will begin soon. For additional information, contact D. Ostberg, TACOM, (313) 574-5814.

Project 5085. Production Techniques for Fabrication of Turbine Recuperator. The current method requires a large number of welds to fabricate components. This project will establish a procedure utilizing a laser beam

to greatly increase welding speed. One set of plates fabricated by laser has been assembled and a second set is in the process of being assembled for the engine test. Upon successful engine test, the prototype production system will be ordered. For additional information, contact S. Goodman, TACOM, (313) 574-6433.

Project 5071. Air Velocity Influences on Fungal Spore Germination. The individual test fungi germination baseline data has been determined using a potato dextrose agar rather than silicon grease. Staining and counting techniques for determining the percent germination of fungal spores has been developed. The air velocity chamber was constructed, tested and proven effective. Baseline data on basic germination characteristics of the individual MIL-STD-810C, Method 508 test fungi have been determined. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Production/Standardization of Coxiella Burnetii Slurries. Rickettsial strains and embryonated eggs have been procured to commence production as soon as the renovated laboratory facility completes the operation readiness inspection. The Ad-California strain of C Burnettii was grown successfully in embryonated eggs and passed in guinea pigs. Producing lots of yolk-sac suspension of sufficient volume to challenge the detection instruments had to be deferred until production of fertile eggs increased. Procedures were established for the production of slurries of this Rickettsia in embryonated eggs, and pools of infected yolk sacs that are free of bacterial contamination have been accumulated for processing into appropriate sized batches of slurry. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 6076. Automated Depot Inspection of Roadwheels. Adhesion, specific gravity, and hardness tests are made on lots containing no more than 50 roadwheels; they require the destruction of approximately 700 roadwheels each year. This project will eliminate destructive lot sampling acceptance by the implementation of an on-line ultrasonic roadwheel inspection system. A preliminary draft hardware design specification has been reviewed and the material ordering has been initiated. For additional information, contact R. Watts, TACOM, (313) 574-8039.

Project 5071. Military Vehicle Rollover Tests. Artillery, vehicle, and electronic conventional test capabilities need to be upgraded to provide more timely, accurate test data for the test and evaluation process. This project will develop a program to upgrade conventional test capabilities at the test activities. The properties of design and operations which contribute to the propensity of military vehicles to rollover during test maneuvers on road operations were analyzed. Five vehicles were identified as having high rollover characteristics. The contractor has developed a field test plan and milestone schedule. The design of a rollover indicator is under way. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Improved Crusher Gages. A prototype gage was developed, built, and tested under laboratory conditions, where it performed well. However, it did not perform as predicted when subjected to weapon firing tests. The prototype was reevaluated and a new gage was built. It was tested under laboratory conditions with favorable results. During firing test, the gage experienced blow-by. Modifications were made to correct the blow-by problem. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 2430. Accept Tester for Common Module Scanner Performance. The contractor responses were received and evaluated. The performance period for the contract was eleven months and resulted in a complete set of test equipment and specifications. Some problems were encountered in digitizing the data. In order to rapidly process the data, some of the nonrelevant data was eliminated. The scan mirror interference pattern analyzer was processed satisfactorily. For additional information, contact L. Doyle, AMMRC, (617) 923-3555.

Project 2425. Optical Testing of Far Infrared Materials. Elations for this project were made with rods used by Siemens, West Germany. The results obtained were excellent. The infrared interferometer setup for homogeneity measurements was completed. Measurements on selected samples indicated that they have to be ground and polished before accurate measurements can be obtained. Interferometry measurements have been completed on the germanium blanks and the samples were analyzed. Most of the interferograms indicated two sets of fringes. The first set was caused by

the sample's wedge angle between front and back suface. The second set was caused by the homogeneity of bulk materials. For additional information, contact R. Spade, AMMRC, (617) 923-3555.

Project 2447. Aerosol Test Apparatus for Biological Detection and Warning. Several aerosol generators have been evaluated along with detector units and miscellaneous hardware components. The design study is basically complete. A procurement package was prepared and forwarded to prospective bidders. A technical team was assembled and they evaluated received proposals. For additional information, contact J. Majeski, AMMRC, (617) 923-3555.

Project 2436. Analytical Chemical Methods for MIL-C-14460. A method was developed for extracting 3NA.OHEDTA from the formulation ingredients which would interfere with its titration. Some refinements are required to shorten and improve the reliability. A buffering system to enhance titration end-point repeatability was selected. For additional information, contact T. Nichols, AMMRC, (617) 923-3555.

Project 2435. Differentiation Between SB283 and SB203 in Paint Pigments. This project has been completed and it appears that the method developed is suspect. The method detects SB253 when this undesirable pigment SB is present. This method will be used when SB has been detected by X-ray spectrometry. For additional information, contact M. Adams, AMMRC, (617) 923-3555.

Project 2402. Knurl Inspection on 155 MM M549 RAP. The design and fabrication of mechanical and optical composition are 95% complete. The electric design is 90% complete and the electrical fabrication is 75% complete. It has been established that the new knurl design will not be used on M549. However, if this effort is successful in inspecting the new knurl samples, QA would take action to implement this technique for the 8 inch M650 RAP round. For additional information, contact G. Zamloot, AMMRC, (617) 923-3555.

Project 5071. Acceptance Test Procedures. Seven Acceptance Test Procedures prepared by other agencies were reviewed and five were prepared and published. Those published covered acceptance tests for 105 mm projectiles, 4.2 inch mortar cannon, 81 mm mortar cannon, and a quality control plan for steel plate. For additional information, contact G. Shelton, TECOM, (301) 671-3677.

Project 5071. On-Line Semiconductor Testing in Nuclear Environment. The integrated circuit test fixture and scanner were checked out. The only item that did not function properly was the transistor section of the scanner. Software has been written to determine the low voltage and current limits for remote testing. The debugging of the software programs and the actual conduct of the tests to determine the required electrical parameters have been completed. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Toxic Gas Measurements During Weapon Firings. Weapons and ammunition were obtained and plans completed for test firings from an M60A1 Tank. A test matrix has been designed which will assess toxic gas buildup while firing from both stationary and moving vehicles. The gas measuring and recording equipment requirements for this task has either been under repair or involved on higher priority programs. Testing is being scheduled. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Safety Evaluation of Ammunition. An investigation is currently under way to establish equivalence between the loose cargo bounce test and tactical transport environment of unpacked materiel. Also, work is under way to determine adequacy of uniform conditions relating to damage. Preparatory work and meetings have resulted in the revision of 14 specifications for ammunition testing. A literature search on solar and air temperature effect on ammunition in both storage and utilization was completed. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 2407. Liquid Chromatography for Epoxy Resin Formulation. A test procedure was designed for fingerprinting the chemical compositions of epoxy resins and prepregs. Sampling procedures were developed and criteria were established for the representative sampling of prepregs. For additional information, contact G. Hagnauer, AMMRC, (617) 923-3555.

Project 5071. Interoperability Test Methodology. Hardware specifications for the software driver have been developed. Link protocols of the field Army artillery, air defense, and electronic warfare/intelligence tactical automated system have beei studied to identify specific hardware and software drivers. For additiona information, contact N. Pentz, TECOM, (301) 671-3677.

Project 8053. CAD/CAM of Parachute Hardware. The production base for small hardware accessories (principally forgings) for parachutes is limited and depends on highly skilled die and mold makers. This project will develop and use computer aided manufacturing techniques for procurement of small hardware parts, including the die and mold manufacture. A computer program has been developed that will design forging dies. This technology greatly reduces the art of designing forging dies to a science. Based upon this report, design rules for use in the development of CAD software were developed. Software for the edger, flattener, blocker, and finish die cavities have been completed. For additional information, contact M. Gustin, NLABS, (617) 653-2211.

Project 8066. Continuous Filament Helmet Preform. The conventional mode of molding the PASGT helmet, weaving Kevlar yarns into fabric cutting preform and laying up, is very wasteful. The purpose of this project is to lay up preforms by continuous yarn and wetting with resin, thus reducing waste and saving 30 to 40 dollars per helmet. Naval Research Laboratories will ballistically characterize continuous filament helmets for casualty reduction evaluation. In order to compare continuous yarn PASGT helmets with the original fabric helmets on an equal Kevlar weight basis, the contract with Brunswick was changed to specify the weight of the molded shell rather than finished weight with components installed. For additional information, contact R. McManus, NLABS, (617) 653-2949.

Project 4264. Inserts and Friction Fillers for Track Rubber Pads. Track pads cut and chunk in rocky or frozen ground resulting in reduced pad life and increased costs and maintenance. This project will establish a process to incorporate filler friction materials in existing formulations which will reduce cutting and chunking. The first set of sample pads has been fabricated and delivered to the test site. A special machine was developed to measure torsional fatigue. The in-house fabrication of a rubber fatigue test machine is well advanced and should be completed soon. For additional information, contact Joseph Fix, TACOM, (313) 574-5331.

Project 3441. Application of High Energy Laser Manufacturing Processes. Cost is a critical factor in conventional welding associated with the manufacture of high volume missile systems such as containers, launchers, etc. The implementation of laser processes has the potential for enormous cost savings. The purpose of this project is to integrate high energy laser technology and computer aided manufacturing controls into systems capable of high production rates and minimal costs. Excellent welds were made for one and one quarter inch thick joints. The tests proved that for welding aluminum, the heat transferred is improved sometimes by a factor of two or more. For additional information, contact J. Melonas, MICOM, (205) 876-5079.

Project 3453. Ground Laser Locator Designator Production Improvements. Optical components are made in small batch quantities requiring high cost attendant labor to attain unusually high precision production capability and testing. This project will improve mass fabrication coating processes and testing of optical components, also improve production methods for the laser optical train. The Naval Weapons Center at China Lake will establish economical production methods for the laser optical train and components in the ground laser designator. At the present time, lens cleanliness is a production problem. For additional information, contact R. Kotler, MICOM, (205) 876-2065.

Project 3454. Low Cost—High Volume Radiographic Inspection. Conventional X-ray inspection using film is unacceptable for high rates of production. This project will utilize a real time radiographic facility with automated, preprogrammed parts handling, also install manipulating fixtures for remote control viewing and analysis. Preliminary design requirements have been defined. Computer systems have been examined, resulting in the identification of HP-1000 as the system that meets the technical and cost requirements. All of the software has been modified and preparation for the industry demonstration is under way. For additional information, contact R. Kotler, MICOM, (205) 876-2065.

Project 5071. Aerosol Biological Particle Size Measuring Standardization. Repairs and calibration of the automatic particle measurement computer system were completed. The system yielded more reproducible values, although the difference between the mean was not significant. The new aerosol facility was completed. A lack of funding delayed completion of this work. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Fast Burst Reactor. Effort has been devoted to evaluation of the effects of reflecting materials on the output characteristics of reactors, particularly the role of various reflectors in changing the nature of the output radiation from the core. Core modification has been completed. The results of this modification have been forwarded to DARCOM for approval for use with the core in this configuration. The test program to establish the characteristics of the reactor in the large irradiation cavity arrangement was completed. This involved establishing the reactivity values of the components of the reactor core. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. In-Bore Radiography Technique Application. The feasibility of an X-ray trigger has been demonstrated. Major components and equipment have been acquired and are being assembled for field testing. The radiation field intensity pattern produced by the 2.3 MV flash X-ray unit was documented. Work has been done to equip the two bombproofs required by manufacturing. The bombproofs and the X-ray trigger are now ready for trial testing, which will be accomplished when an appropriate firing program becomes available. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Lidar Feasibility Test. Tests were conducted to measure smoke/obscurant characteristics and behavior using lidar type equipment. The data generated in the previously conducted field test of a lidar type system has been evaluated. Based on these results, a contract has been awarded for a lidar system modified to meet smoke munition evaluation requirements. For additional information, contact G. Shelton, TECOM, (301) 671-3677.

Project 2409. Emission Spectrograph Analysis of Maraging Steel Plasma. The instrument vendor has completed the profiling of 40 slits and is currently in the process of calibrating the instrument. The results of the cobalt, molybdenum, and nickel compare favorably with the wet chemical values. The percent relative standard deviations were 0.12 to 0.62 for cobalt, 0.05 to 1.42 for molybdenum, and 0.38 to 0.67 for nickel—good for high concentrations. For additional information, contact F. Valente, AMMRC, (617) 923-3555.

Project 2456. Test System for Real Time Mechanical Wear Assessment. Arrangements have been made with the 94th Aviation Detachment to obtain oil samples for ferrographic analysis. A number of UH-1 and OH-59 helicopter engines, transmissions, and rotors are assigned to this program. Periodic oil samples will be taken. For additional information, contact S. Acquaviva, AMMRC, (617) 923-3555.

Project 2405. Burn Time Test for Zirconium Powder in Thermal Battery. The review and analysis of various existing open train burn time techniques has been completed. The desirable features are being incorporated into the new system. The areas of concentration are measuring the actual burn time and powder preparation. The system is capable of measuring the burn rate of the zirconium powder train, 0-20, as well as an interim distance of 10-20. Work is proceeding on the fabrication of a device for making accurate burn time measurements on a shorter powder train. For additional information, contact P. Wong, AMMRC, (617) 923-3555.

Project 2453. Thickness Measurement of Nonmagnetic Coatings. After investigating thickness measurement equipment manufacturers, it was determined that they do not offer a special probe nor do they incorporate their equipment into measurement systems. Therefore, some fixturing will be done in-house. The prototype chrome plating thickness gage head has been successfully tested on the 120 mm smoothbore gun tube. This demonstrated the feasibility of measuring chrome plating thickness with a fixtured probe. For additional information, contact R. Campolmi, AMMRC, (617) 923-3555.

Project 2451. Gun Tube Roundness Measurement. The current concept consists of one head which will combine 2 point and 3 point measuring systems. By comparing the

readings electronically the roundness of the tube can be obtained. A technical proposal for the ancillary electronic equipment has been reviewed and found acceptable. Bids are currently being solicited for the machining of the fixtures. The gage head was delivered, inspected, and accepted. The deliveries of the electronic system, LVDT cartridges, and amplifiers are scheduled. For additional information, contact R. Campolmi, AMMRC, (617) 923-3555.

Project 8190. MMT Improved Blisk-Impeller Cutter Life. Milling cutter cost associated with the blisk and impeller for the T-700 engine is averaging $2540 per engine and is considered excessively high. This project will investigate cutter parameters which affect cutter life - such as feeds, speeds, geometry, and cutting fluids - and thereby develop a manufacturing technology to reduce cutter costs by 50 percent. For additional information, contact J. Corwin, TSARCOM, (314) 263-2220.

Project 5071. Backspalling Characteristics. Testing has been completed on dual hardness steel plates in thicknesses of 3/8, 1/2, and 5/8 inch. Test results indicate that the backspalling which occurs on 5/8 inch plate may not be acceptable. Another ballistic test was conducted on dual hardness steel armor. Problems associated with backspall test requirements were discussed with various contractors and Army personnel. The largest exit hole diameter has been used as the backspall criteria. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Projectile Eddy Current Inspection. New eddy current probes for the test unit were received. Test technology was demonstrated which reliably detects artificially induced cracks in the nose area of projectiles with hand held probes. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Electrostatic Generation and Precipitation. A man sized Faraday cage has been constructed. Initial tests indicate that it will measure the static charge on a man clothing system. A method of calibrating the man sized Faraday cage has been established. The photographic documentation of the equipment configuration will complete the data acquisition phase of this task. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. General purpose Bit Slice Microcomputer. A review of the current bit slice design revealed several problems. A study was made of the current technology to determine the best solution to the current bit slice shortcomings. The micro 2910 bit slice ship device was chosen as a replacement. A general purpose computer interface has been designed and placed on the advanced micro device's 2910 bit slice microprogram controller chip. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Electromagnetic Radiation Effects/Susceptibility of Army Materiel. A technique for detecting 3MA of current in electro-explosive devices was developed. This technique consists of injecting a bias current through a thermistor. The change in the voltage across the thermistor is indirectly caused by a change in current. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Smoke Sampling/Characterization. The data were collected from 40 wind tunnel tests with fog/infrared materials. The data requirements have been completed. Tests have been initiated to eliminate the problem of mounted sampler movement on exposure to explosive shock of the smoke round. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Integrated Test Data Acquisition. Three integration test networks employing optical fiber data links have been built. Two of these systems have been bench tested and have had limited field tests. A third prototype is being prepared for testing. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Improved Vulnerability Testing. An improved intra-range communication system has been designed. The requirements for new ranges and test site locations have been established and approved. The requirements for new power transmission lines, data, and inter-range facilities are now being defined. For additional information, contact N. Pentz, TECOM (301) 671-3677.

Project 5071. Shock and Blast Effects From Staballoy Penetration. A test firing plan is being prepared for the purpose of determining shock and blast levels which can be expected during typical test of staballoy projectiles. The literature search was completed. A temporary enclosure was constructed and instrumented to test shock and blast levels of the staballoy projectiles on armor targets. A study was initiated to determine the effects of firing depleted uranium projectiles into a target enclosure. This information was to be used in the design of the target enclosure to be built. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Certification of Loose Cargo Bounce Test. A sample hardware monitor was fabricated and tested. Various modules consisting of 46 tuned reed sets with bonded fatigue gauges and strain gauges have been built. Two tests on the package tester have been performed at 300 rpm. The data from these tests have been analyzed. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Improved Engine Wear Analysis. Work on making and analyzing known synthetic suspensions of wear products will be pursued. Samples of both new and used engine and final drive oils have been obtained. Baseline analyses by both atomic absorption spectrometry and emission spectrometry have been completed. Of the various methods tested to separate the dissolved organometallic compounds from suspended metallic particles in oils, separation by column chromatography is the most promising but needs further development. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Test Automation Development. Extensive work has been done on development of mainsite concepts and applications. This work will culminate in an overall definition, design, and implementation of an automated test system capable of handling large computer oriented C3I equipment. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Receiver Operating Characteristics Measurements. A technical literature review was initiated. Several sources of applicable theoretical investigations were determined and reviewed. Algorithms are being evaluated. Weapon system test instrument test requirements are being generated. The preliminary literature search of the texts and other technical documents has been completed. A fast Fourier transform system was acquired for preliminary background work applicable to receiver operating characteristic investigations. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Solar Powered Instrumentation Van. The van design was completed. Tests were run on the thermoelectric heating/cooling units. A search was conducted for control function components. The design of the heating and cooling system was completed. The procurement actions on all materials and equipment have been finalized and 90% of the items have been received. Software program for control and monitoring of the heating, cooling, and power usage has been written and 80% debugged. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Interoperability Test Methodology. This work will be accomplished under contract. The SOW has been developed. Coordination with other interoperability related working groups has been established to define the state of the art testing capabilities and concepts. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

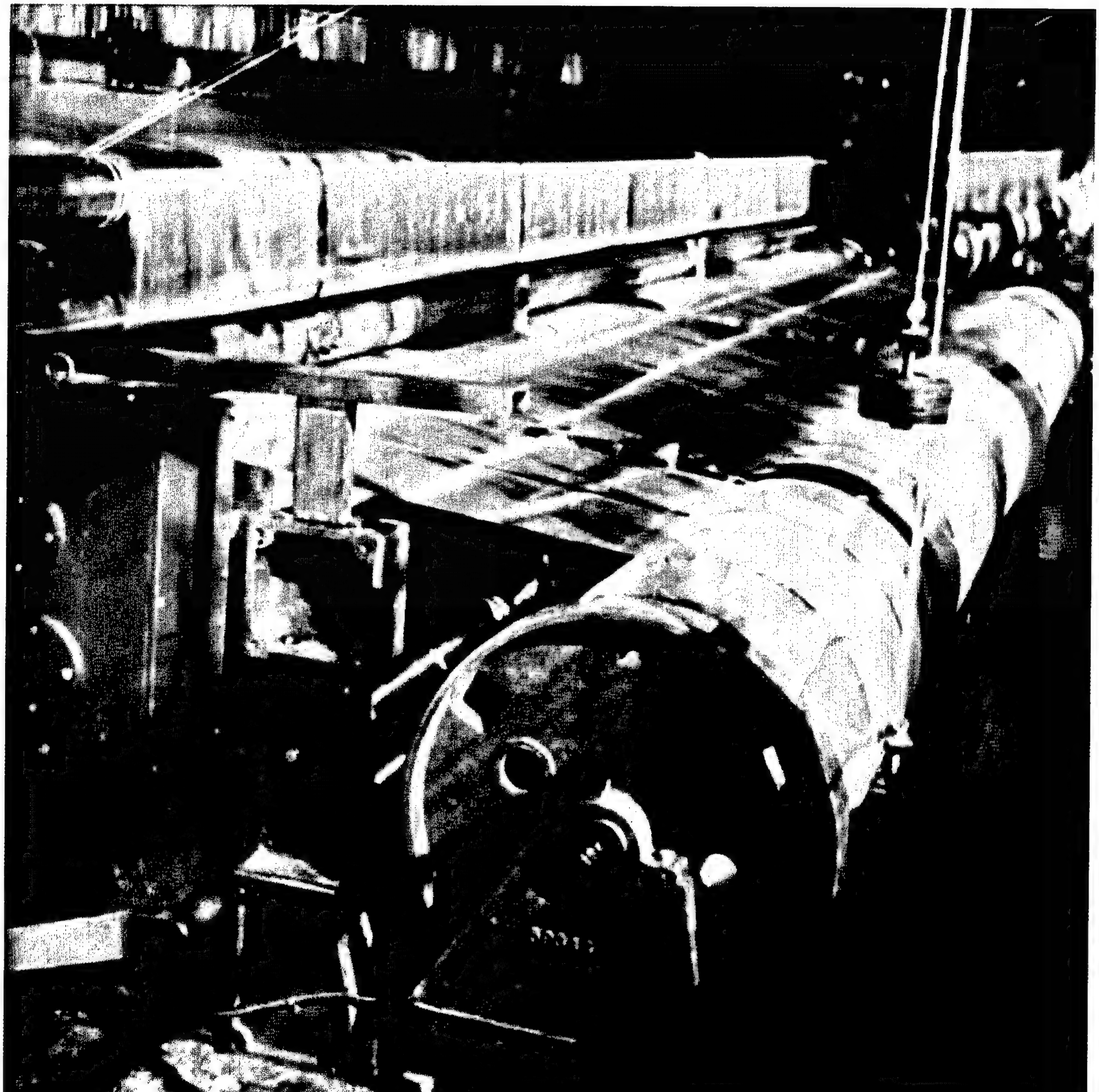
Project 5071. Computer Aided Test Planning. Initial drafts have been completed for the following test plan segments - introduction, materiel description, test objectives and scope, individual subtests for receipt inspection, storage and performance, reliability, logistics, and safety and human factors. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

Project 5071. Gamma Dosimetry Improvement and Modernization Program. The measuring of gamma dose is best accomplished by the use of CAF2 TLD S. A procedure for acceptance testing of a large number of CAF2 TLD S has been established. Four new pin diodes are being tested. For additional information, contact N. Pentz, TECOM, (301) 671-3677.

US Army
ManTech Journal

Achieving A Breakthrough

Volume 7/Number 3/1982



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Contents

1 Comments by the Editor

3 Production Validation of Electronic Fuzes

8 Improving T700 Nozzle Manufacture

14 Beam Lead Device Costs Reduced

17 Pneumatic Mechanical High Energy Forging

22 Compact, Rugged Telemetry Transmitter

25 Selective Surface Finish Cuts Costs

27 Internal Shear Forging for Missiles

31 Ferrite Phase Shifters From Arc Plasma

35 Plasma Spray for Millimeter Wave Shifters

38 Brief Status Reports

Inside Back Cover—Upcoming Events

ABOUT THE COVER:

Large collapsible fuel tanks can be woven on looms such as this one which can handle tubular fabrics up to 90 feet wide. In work sponsored by the U.S. Army Mobility Equipment Research and Development Command, multiple harness wide fabric looms have been developed that are capable of producing such seamless tubular fabrics. Weaving of a tubular fabric is similar to the production of flat fabrics, except that there are two sets of warp yarns, one set to form the top of the tube and the other set to form the bottom. The filling yarns are inserted through the top set of yarns on one pass across the loom and then through the bottom set of yarns as the shuttle returns. It is critical to minimize weaving irregularities at the two edge turnaround points. For further information, contact Richard W. Helmke, (703) 664-5176.

THE MANTECH JOURNAL is prepared quarterly for the U.S. Army under the sponsorship of the Directorate for Manufacturing Technology, DARCOM, by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

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Comments by the Editor

RAYMOND L. FARROW

It has been interesting for those of us involved with the production of the U.S. Army ManTech Journal to note that one of our associates—Stephen Robinson, who has served on the magazine's staff as Technical Consultant for the U.S. Army Armament Materiel Readiness Command—has been selected to manage the recently announced $235 million renovation of facilities at Rock Island Arsenal. Steve's replacement as Technical Consultant on the magazine's Advisory Staff is Mr. W. Dennis Dunlap. We have been pleased to be associated with Steve during the past three years and appreciate very much his help and cooperation in setting policy for the Journal. As Chief of Project Rearm at Rock Island Arsenal, he has promised the magazine staff a close look at the modernization program which he is overseeing, and we plan to carry an article on the project in the near future.

This issue of the Journal features the largest number of Brief Status Reports that we have carried to date, in response to the wishes of our readers who have been universal in their requests for more brief, current reports on ongoing projects in the Army's MM&T program. The preponderance of the briefs in this issue are on munitions and weapons projects of the Munitions Production Base Modernization Agency which are being carried out at various Army Commands. We will report on a more homogeneous mix of projects of all types of MM&T work in future issues, now that we have nearly completed a comprehensive update on all current Army projects.

The article on proving the functionability of Army fuzes simultaneous with their production is an example of the large savings in dollars possible from a well conceived, efficiently implemented mantech program. The Harry Diamond Laboratory staff involved should be commended for their accomplishment and should be proud of the economic impact of the program.

Some very sophisticated production technologies were put into effect by the Army's Aviation R&D Command on the manufacture of the T700 turbine nozzle. This article outlines the development of a technique that uses computer assisted electrical discharge machining along with area measurements via automated optical devices. The report should be of interest to many fabricators who are faced with the challenge of producing components with complex surfaces to extremely close tolerances.

One of several very short articles in this issue of the Army ManTech Journal is featured on page 8. This report is about another Electronics Command project conducted by Jim Kelly, who has authored previous articles for the Journal. The project established important guidelines to be followed in the manufacture of the highly reliable beam lead devices that have presented a challenge to production engineers for some time.

Numerous cost advantages from producing forgings by high energy rate forging can now be realized following the completion of a project on this technology by ARRCOM.

The economic leverage existent from the fact that so many components of heavy combat equipment are made by forging means that enormous cost savings will result from the determination of how best to use this technology. The article on page 17 highlights this work.

More efficient telemetry of artillery projectiles is the result of the successful completion of a project described in an article on page 22 in which the Harry Diamond Laboratories developed a new compact crystal controlled L-band transmitter that is much more rugged than past such devices.

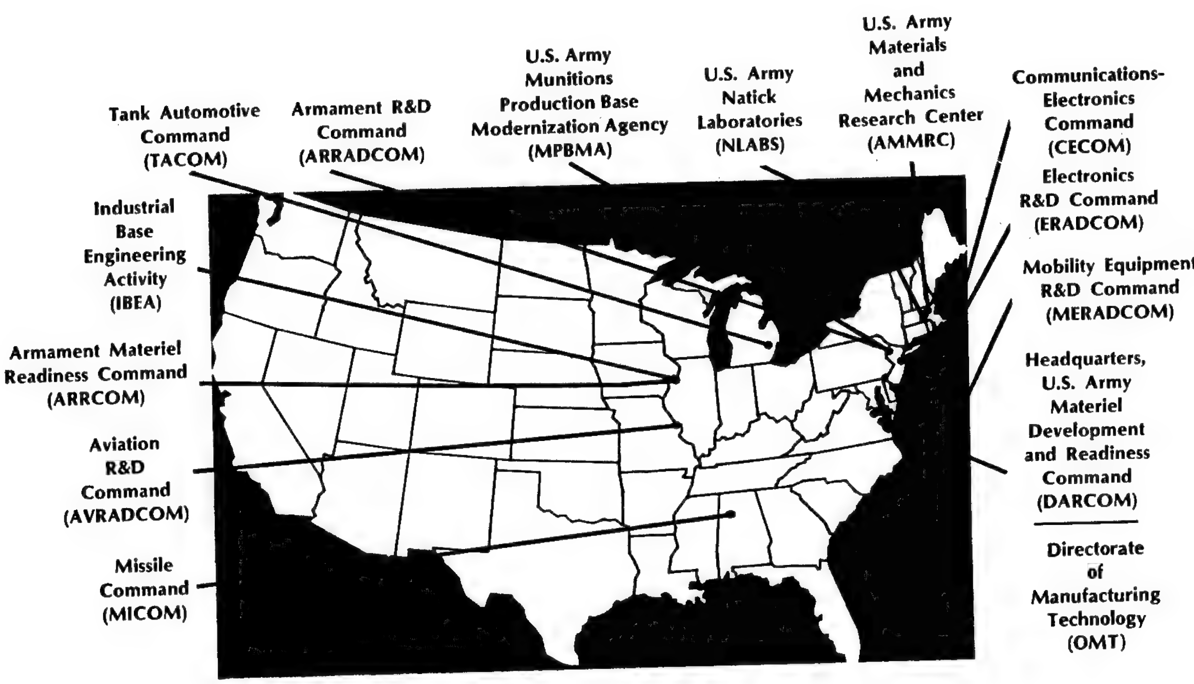
The high cost of over specification of surface finishes on gun components was determined by a project conducted at Watervliet Arsenal which established firm data regarding cost factors related to this type of production. The study was most significant, pinpointing areas where designers could reduce costs of production markedly simply by specifying only those surface finishes that are necessary for the functioning of a particular part, rather than "playing it safe" by over specifying requirements beyond those needed. This project's findings will make dramatic cost savings possible when taken into consideration at the design stage.

Substantial cost savings and improved mechanical properties will result in missile primary structures produced as monolithic structures by internal shear forging, as indicated by the findings of a mantech project sponsored by the Army Missile Command. Components of greater strength result from the thermomechanical treatment, and improved dimensional stability and decreased residual stresses have been observed, pointing to continuing improvement in product. The near net shape components fabriccated with this technology contribute to sharp cost savings.

Arc plasma spray technology has been put to excellent use on phase shifter fabrication by the Army's electronics agencies, as described in a pair of articles on pages 31 and 35. In the first article, the remarkable flexibility of the arc plasma spray technique lends itself well to the production demands of small batches of lithium ferrite phase shifters whose design may continually be modified. An economical method of fabrication that can accommodate design changes easily is a perfect match with the component characteristics.

The second article of this duo describes how arc plasma spray techniques make possible economical production of millimeter wave phasors whose designs are characterized by extremely close tolerances and whose ultimate performance is affected critically by the uniformity of the component's structure.

DARCOM Manufacturing Methods and Technology Community

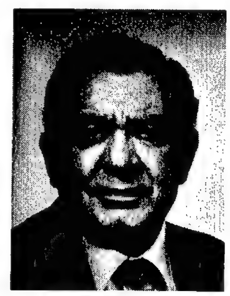


Prototype Presents Fewer Problems

Production Validation of Electronic Fuzes

HARRY E. HILL, JR. is Chief, Fabrication Technology, U.S. Army Harry Diamond Laboratories, Adelphi, Maryland. He received his B.S. in Mechanical Engineering from Duke University in 1967 and has done graduate work in Systems Engineering at George Washington University. He has been involved with R&D and/or mechanical fabrication throughout his professional career.

FRANK L. TEVELOW is a project engineer in the Harry Diamond Laboratories Environmental Test Branch currently evaluating the effects of logistical transportation vibration on fuzes and developing criteria for random vibration test specifications to replace swept sinusoidal test procedures. His entire career has been at HDL, where he has been involved in the design, testing, and evaluation of fuzes. From 1960 to 1967 he did basic research on the interaction of X-band radiation with shock tube generated ionized gases. From 1974 to 1978 he was technical assistant to the Chief, Research and Engineering Support Division, coordinating and overseeing the operational and architectural design specifications for relocation of the division's facilities from Washington to new quarters at Adelphi, Maryland, Mr. Tevelow received his B.S. in Physics from George Washington University in 1957.



JOHN J. FURLANI is Chief of the Mechanical Technology Branch at the Harry Diamond Laboratories, Adelphi, Maryland, where he has acquired over 30 years of experience in the research, development, and production of electromechanical and electronics fuzing and other ordnance systems. He is an engineering graduate from the City College of New York and has attended graduate school at Maryland University. He is a member of ASME, SME, and ADPA. He has authored or coauthored more than 30 technical reports and has several patents relating to fuzing, safing, and arming.

Savings of over 17 million dollars are projected as a result of the successful development of a system of validating electronic fuze quality during production in a program carried out at the Army's Harry Diamond Laboratories for the U.S. Army Electronics Research and Development Command. The methodology was the result of a deliberate, systematic approach to the long standing problem of efficiently proving the functionability of the Army's artillery fuzes when produced at high rates.

Economic Justification

An economic analysis was made comparing the predicted costs of fuzes in production under the current system versus these costs with the Prototype Validation Facility (PVF) in operation. This analysis was based on the assumption that the utilization of the PVF during development will provide a head start toward the later production phase. This was estimated to result in a 10 percent reduction in unit production cost. Over an 11 year period, 11 projects were considered.

The analysis concluded that a total present value of savings amounted to 17.03 million dollars, a savings to investment ratio of 2.32, and a rate of return on investment of 22 percent. These figures, of course include the cost of construction, equipment purchase, and operating expenses.

The principal objective of this study by the Harry Diamond Laboratories for the U.S. Army Research and Development Command was the definition of a facility that could manufacture and test prototype electronic fuzes using advanced state of the art production techniques. This objective has been realized. Also, the technologies and equipment necessary to apply them have been enumerated, the facility has been laid out in detail, and a multiyear plan for implementation of the findings of this study has been developed.

NOTE: This manufacturing technology project that was conducted by Harry Diamond Laboratories was funded by the U.S. Army Electronics Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The HDL Point of Contact for more information is Mr. John J. Furlani, (202) 394-3124.

Semiconductor Research

Semiconductor R&D personnel at HDL have been producing devices for electronic fuzes, radars, and optical systems for many years. They have been innovators in semiconductor technology; for example, they developed the two step reduction process for mask making and the use of the step and repeat camera for generating large arrays. Much of their current work is directed toward the development of radiation hardened semiconductor devices for military use. The trends developing in this area are the increased use of silicon monolithic devices and the integration of fuze functions. The emphasis will be on bipolar and complementary metal oxide semiconductors. The facilities proposed will allow for a practical transition between demonstrating feasibility and ensuring producibility. The area will have precise environmental control to minimize contamination, an ion implanter for the accurate placement of impurities, injection molded plastics encapsulating for lower costs, and semiautomatic equipment for process control.

Electromechanics

Electromechanical experts identified two separate areas where improvements are required. The first area identified was the support area of mechanical parts fabrication. The use of low cost fabrication techniques such as stamping, coining, casting, sintering, and molding is desirable in many electromechanical components, including safety and arming (S&A) devices. These capabilities are necessary for component fabrication so that assembly and test operations will be performed on similar items. Because of stringent safety requirements, extensive testing is required of S&A mechanisms, and process changes often require the repetition of these tests.

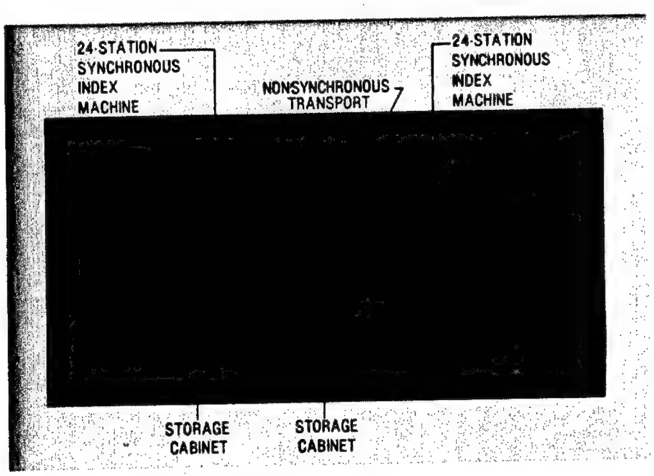


Figure 1

The second area identified was mechanized assembly, testing, and inspection. This is integral to the design of the mechanisms and has the potential of large savings. Currently, these are labor intensive areas and the work is done by hand. The emphasis will be on mechanization and merging of the assembly and test operations. Mechanization will also offer improved safety in the fabrication area (Figure 1).

Thick film microelectronic fabrication and assembly (Figure 2) is a technology recently applied to electronic fuze circuits. It is not only an emerging technology, but one that currently is expensive for military systems. The increasing use of multifunction fuzes and the increasing interest in fuzing smaller munitions are causing greater use of this technology. Problems that need to be worked on in this area are

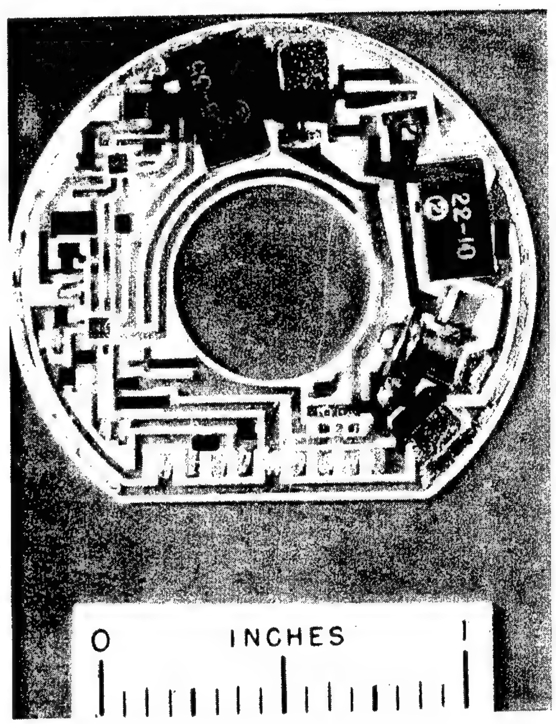


Figure 2

(1) The print and fire parameters that allow the needed fine line conductor patterns and achieve resistor trimming
(2) Adoption of active resistor trimming compatible with high production rates

(3) Automatic wire bonding with a single visual alignment
(4) Development of low cost packaging techniques for the ordnance environment.

The printed wiring board fabrication area will allow for additive and subtractive board processing and multilayer board fabrication. Printed wiring boards will continue to be used in electronic fuzes when space permits and in other applications because they are rugged and relatively inexpensive. In addition, printed circuit board techniques are used in the fabrication of antennas and rf stripline circuitry. This area will provide the capability for fabricating printed circuits in large arrays which reduce handling and are desirable with automatic insertion equipment. New processes will also be introduced such as the additive process, which uses less copper and results in less waste, and multilayer board fabrication, which increases circuit density and allows printed circuit techniques to be used on more complex circuitry.

The electronic board assembly area will emphasize machine insertion of components. The relatively low cost of printed circuit boards compared to thin and thick film circuit methods and the proven ruggedness of these subassemblies in the ordnance environment virtually assures their continued use. Modern hand assembly stations and machine insertion will both be used. The high density of components in some electronic applications requires partial or complete hand assembly. Whenever possible, machine insertion will be used to decrease hand labor requirements for these assemblies. The use of large array circuits for machine insertion, mass soldering, and automatic lead cutting all effect circuit topology. Circuits assembled in this facility will have demonstrated compatibility with all of these mass production techniques.

Fuze Power Sources

Most of the research and development that extends the state of the art in power supplies for electronic fuzes is conducted by the Government. Safety requirements, limited space, and the extended shelf life of electronic fuze power supplies make them unique. Four power supply types meet these requirements: liquid reserve (Figure 3), thermal reserve, turboalternator, and fluidic generator. The technology base for these is highly specialized and radically different from the commercial battery industry. The power supply area is already heavily committed to prototype power supply fabrication. The equipment that power supply personnel are proposing will augment what they already have with the emphasis on techniques and processes that are very close to or can be readily adapted to those used by commercial manufacturers. In addition,

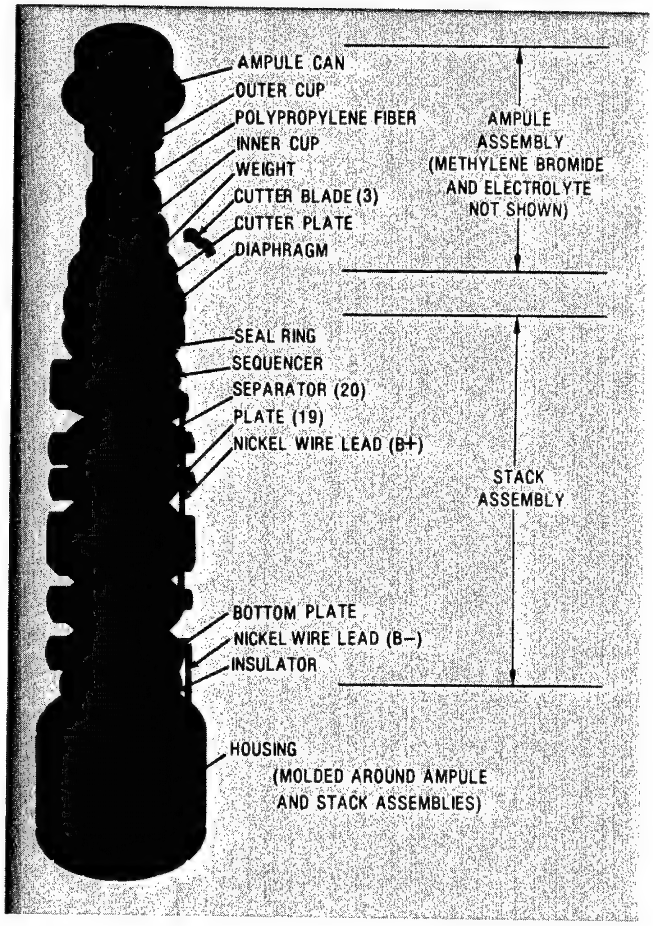


Figure 3

materials will be evaluated for their suitability to satisfy performance criteria and for their adaptability in fabricating the required power supply.

Environmental, Electronic Testing

The goal of the environmental test area is to achieve accelerated conventional environmental tests. This is necessary so that the environmental testing can keep pace with the increased rates of mechanized assembly. If production rates increase, the current level of confidence can be maintained, and if production rates remain constant, the testing level of confidence can be increased. The high cost of field tests and the time delay between fabrication and field testing make accelerated environmental testing desirable. Field tests will not be eliminated, but accelerated environmental testing will provide a quick reaction screening of production units and allow for early detection of faulty production units. The PVF can provide production

items. This will result in improved correlation of test results to final field performance. These efforts—combined with recent advances in the technology of simulated environmental testing—have the potential of replacing field testing, after initial correlation, with simulated environmental testing. The electronic test area is where the proper functioning of the fuze is validated. Experience has shown that on-line testing of electronic fuzes (particularly the radiating type) is a cricital factor in the production process. Design and fabrication of such equipment has accompanied each fuze development with the specifications and often the equipment itself being given to the production contractor for inclusion on the production line. Numerous measurement and inspection techniques already exist and are in use in automatic fabrication at assembly lines for commercial mechanical and electronic items. Many of these methods are directly applicable to fuze manufacture and can be incorporated into an automatic line with a high degree of confidence. Other aspects of fuze testing, however, particularly special conditions applying to radiation type proximity fuzes, have no direct counterpart in high production items on the commercial market. It is on the second type of testing that the prototype validation facility will concentrate. Recent advances in microprocessors and related automatic equipment have permitted an expanded and more sophisticated role for such equipment. Mechanical handling, automatic cycling of tests, and marking of tested fuzes will be included. Minicomputer control of the microprocessor controlled test station will provide flexibility and real time data acquisition.

Electronic Assembly

The electronic assembly area examined two problems: the final assembly of electronic fuzes and methods of nonstandard fastening. The relative merits of rotary or synchronous machines and nonsynchronous transfer machines were considered in some detail, and it was concluded that rotary tables were better, but for final fuze assembly the nonsynchronous system is advantageous and for this application such a system is proposed. Two types of nonstandard fastening methods were proposed: ultrasonic and laser. This equipment will be used to support both the electromechanical and the power supply areas. Several ultrasonic bonders were proposed to provide the needed range of frequencies and power levels. Two laser systems were also proposed: a 200 to 500 W yttrium aluminum garnet (YAG) or ruby laser and a 1 to 5 kW carbon dioxide laser. The ability of this type of equipment to concentrate on small areas minimizes the possibility of damaging other areas or components on the work piece. Both technologies are being adopted by industry for high rate quality production because of their controllability and a resultant low reject rate. The mechanical parts fabrication area will operate in support of the rest of the facility. The primary deficiencies cited by development groups were the lack of powdered metal and die casting technology. The addition of these capabilities accounts for most of the effort. Special design considerations, safety requirements, and physical properties of the parts require the use of production like parts during development testing. Because of the large inventory of equipment and extensive use of screw machine parts, two screw machines were specified. These parts are not the most desired, because of dependence on foreign equipment, but until proven alternatives are developed they will continue to be used in quantity in electromechanical devices. The current numerically controlled machine tool and plastic molding equipment is considered necessary and sufficient for proper operation of the overall facility. A general shop and inspection area is also necessary to support the facility. These capabilities are also enumerated.

Computer Support Important

There are a number of areas within the Prototype Validation Facility where computer support is required. This support will be provided by a combination of minicomputers and intelligent terminals that will tie into existing computer facilities at HDL. Management will use these facilities for scheduling, inventory control, and costing information. Computer aided design and manufacturing will be coordinated with the NC equipment throughout the facility. Portable terminals will provide real time data acquisition from operating equipment and online test setups. These data can then be analyzed and/or used as inputs to simulation programs. Since the PVF will have single pieces of equipment when the production facility may have many, the cost of end items in production will rely to some extent on the ability to simulate the proposed production facility on computers. Once each of the areas was defined, the individual areas were integrated into one combined facility. This involved the removal of duplications and the addition of areas overlooked in the separate chapters.

Work Level vs. Staffing

Of real concern is the problem of maintaining the PVF capability when the work level is low. This problem was considered early in the study and was recognized as a critical factor in assessing the practicality of the PVF. It was concluded that if an element of the PVF required the permanent assignment of specialists for operation then it was not practical for inclusion. As a result, each of the several

study groups was informed that they should approach the problem with the assumption that the PVF activity could be maintained with existing staff. Further, if specialized knowledge was required for the operation of certain types of equipment, it would be obtained by training and not by recruiting additional staff. This was considered to be a reasonable limitation since equipment already existed and was being used to fabricate prototypes. With additional training, existing staff could become proficient in the operation of the equipment required for the PVF. Further, since the emphasis was being placed on producibility, more prototypes would be fabricated on the new and less on the old equipment. Thus, the overall workload would not be significantly increased.

Mobilization Readiness Achieved

There is strong rationale to support the conclusion that a prototype design—using industrial type fabrication methods made on production like equipment that is validated by various test methods before release for production engineering—will present fewer problems and fewer scheduling delays, and will result in a cheaper, more reliable end product. Computer support, on-line test data, and simulation testing will also provide documented test data packages against which laser production run units can be measured. Because of the various production options, HDL personnel would be used efficiently by shifting people among the various areas as work loads change. This will provide a group of people, well versed in the various production areas, that will be able to go to contractor plants, consult with and advise the contractor in setting up production lines, pinpoint problem areas, and assist generally. At least one individual will be responsible for overseeing and coordinating all operations, including value engineering, design to cost, quality assurance, reliability, and development of prototype test data packages. Another individual will act as the library and conduit for collecting, staying abreast of, and disseminating state of the art and technological advances relating to product engineering and automation. The PVF group will form a reservoir of in-house expertise that will stay abreast of the latest advances in production technology areas pertinent to electronic devices, including fuzing. They will thus be in a position to advise Army headquarters staff regarding electronic technology production, thus assuring a strong defense posture complemented by mobilization readiness.

Skepticism at the Beginning

This study was the joint effort of nine branches at HDL. The distribution of work was recommended by a Steering Committee that convened to review this project. The committee then decided that the project should be managed by the Engineering Support Branch and that tasks related to specific component areas would be delegated to the appropriate branches within HDL. It was felt that this method would provide for the broadest input to the project within HDL at the lowest cost. The initial reaction of several branches to the prototype validation facility (PVF) concept was skepticism. Skeptical or not, they began to examine how they were doing things, what industry was doing, the costs of changing designs after testing, and problems that now occur in the manufacturing of electronic fuzes. Attitudes gradually changed, and skeptics became advocates. The conversions first occurred within each area of expertise and gradually expanded into overlapping areas. Not all technical groups support the need for the complete facility. This is primarily because the problems peculiar to one area are not understood by those in other disciplines. It is the consensus of those involved that the evolved plan (Figure 4) should be implemented and that all elements should be included. The prototype validation facility represents a reemphasis of production aspects during development. This had been considered during development, but the PVF now provides the tools for verification of producibility. Not only will the tools be provided, but the development personnel will be actively involved, allowing them to benefit from this experience. Knowledge gained during prototype fabrication will be used to aid the management of contractors' efforts during development and later during the production phase. Further, production techniques specific to a particular design will be passed along to the contractor to reduce transition time from development to production.

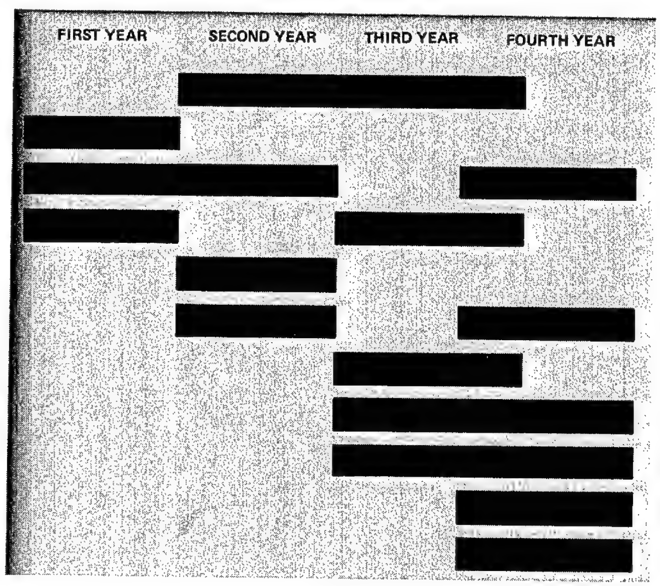


Figure 4

Three Part Program Focus

Improving T700 Nozzle Manufacture

JONATHAN PRATCHER is a Project Engineer at the U.S. Army Aviation Research and Development Command, where he works on all categories of testing and inspection activities for the manufacturing technology group. He has worked at AVRADCOM for four years, following eight years of work at McDonnel-Douglas. He received his B.S. in Industrial Technology from Tuskegee Institute in 1971.

Photograph Unavailable

Computer assisted EDM, cooling flow measurements by IR, and automated optical area measurement have been utilized to improve T700 turbine nozzle manufacturing. In a program conducted by the General Electric Company, Aircraft Engine Group, in Lynn, Massachusetts and Evendale, Ohio, this work was sponsored by the U.S. Army Aviation Research and Development Command.

Programmable EDM Reduces Time

The first part of this work consisted of using the current EDM process and adding a new concept utilizing a computer assisted power supply to the nozzle airfoil trailing edge cooling holes. A programmable EDM power supply will indeed reduce the cut time for the T700 trailing edge closed slot operation by one third. However, maximum machining rate obtainable could not be used due to micro cracking. Further, the reduction in planned time that can be achieved on this operation will require approximately 1250 sets to recover the investment cost.

To carry out this task effort, the Manufacturing Technology Laboratory at Evendale conducted a development program to assess the potential benefits of a programmable electrical dishcharge machining (EDM) power supply for a T700 turbine component application. A programmable EDM power supply permits the selection of a "parameter profile" which is optimum for varying machining conditions during the course of an electrical discharge machining operation. This allows minimum cut time commensurate with required geometry and surface characteristics—by machine control.

Since it would be totally impractical to attempt EDM electrical power supply variations in a production environment, the decision was made to perform the experiments at the Manufacturing Technology Laboratory.

The trailing edge cooling holes in the T700 high pressure turbine nozzle vane are close toleranced and of a size and depth which challenge existing EDM capabilities for low cost manufacture. The established electrical discharge machining practice on this application is to use constant parameters for the entire cut. These parameters are governed primarily by the machining conditions at the "entrance" and "exit" of the cut where dielectric flushing and other process requirements are marginal. The EDM cut time on this operation at the onset of this program was sixteen minutes. A different production supply introduced during the program enabled reduction of the cut time to twelve minutes. This application was, therefore, thought to be amenable to improvement with the use of a programmable power supply.

NOTE: This manufacturing technology project that was conducted by General Electric was funded by the U.S. Army Aviation R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVRADCOM Point of Contact for more information is Mr. Jonathan Pratcher, (314) 263-1625.

The Testing and Equipment

The machining optimization tests and demonstration hardware were run on a Raycon EDM machine equipped with a Raycon programmable power supply Model CP60. The EDM head movement is controlled by a hydraulic servo and has a one inch stroke. The CP60 is built around a microprocessor which continuously monitors the system operation and issues the appropriate commands needed to implement an EDM operation. It also checks for fault conditions and operator commands and provides interface with the operator via keyboard or permanent memory unit.

In this development activity, process parameters were entered through the keyboard. The parameters which can be programmed are: sequence time, pulse time, interval time, arc level, arc suppress, short delay, servo feed, servo response, polarity, pulse, and gap extender.

A production shuttle (part holder) for EDM of T700 High Pressure Turbine Nozzle (HPTN) vane trailing edge holes was adapted to the laboratory EDM machine. Then a duplicate of the electrode guide mechanism was built and installed on the laboratory machine. Production electrodes were used for all tests and demonstration hardware. Next, preliminary trial runs were made using round electrodes and flat work pieces to verify capability to perform the planned tasks.

To establish a base for comparative results, it was necessary to verify production machining times on the CP60 power supply. The production power supplies are not the same as the laboratory supply in some respects other than the microprocessor; however, the shop times of 16 and 12 minutes per cut were approximated on the CP60.

Experiments were run in flat work pieces to optimize the EDM parameters for that portion of the cut when the electrode and workpiece are "fully engaged" and the machining conditions permit the maximum penetration rate and lower overall cut time. A series of four designed experiments were run and the results of each were analyzed using statistical techniques. Parameters for each test were then modified in directions indicated by the analysis.

Gentle parameters for EDM at the "entrance" and "exit" of the cut were determined and evaluated. These parameters are used for only a short period of time during the cut and extensive testing was not necessary. The parameters were set at "safe" values based on prior experience. The principal responses measured were net penetration rate, slot dimensions, and metallography.

Although a lot consisting of four production parts was run to verify parameters in the actual workpiece geometry, a log of twenty production parts was run with optimized parameters to demonstrate the process.

Test Results

Four separate experiments were conducted. The first—to optimize the "fully engaged" parameters—was built around the limits of the power supply capability for each controllable characteristic in an attempt to avoid guiding the test with preconceived ideas. The extreme combinations produced malfunctions in every instance, and no measurable EDM took place.

The second consisted of 32 runs and 9 factors. Statistical analysis identified that (1) servo feed, servo response, and gap extender had little effect on measured responses, (2) net travel increases significantly with increasing current level, (3) electrode wear decreases significantly with increasing time and decreasing current level, (4) electrode wear increases with interaction of pulse time and arc level, and (5) very high interval times produce very slow machining rates.

The third test showed that (1) net travel increases significantly with current level and decreases moderately with increasing arc level, (2) electrode wear increases significantly with increasing current level, (3) overcut increases significantly with increasing pulse time, current level, and servo response, (4) micro cracking is significantly affected by current level, interval time, short delay, and servo feed, (5) maximum penetration rates obtained could not be used in production due to micro cracking beyond allowable limits, and (6) optimum machining conditions for the "fully engaged" cut, based on the analysis, are as shown below with asterisks indicating recommended settings.

Optimum EDM Conditions

	Net Travel	Wear Ratio	Crack Length
Pulse	11	55	11
Interval	—	250	350
Current Level	16	10	10
Arc Level	7	9	7
Arc Suppress	7	9	—
Short Delay	—	—	3
Servo Feed	—	—	14
Servo Response	—	—	—

The last experiment consisted of machining four production parts using values intermediate to those shown to be optimum statistically. Micro examination of the parts showed redeposited material or "globules" near print limit. Recast and micro cracks were well within print

limits, and the average EDM cut time was 9½ minutes. A lot of twenty production parts was then machined using the procedure.

Cooling Flow Measurements by IR

The second part of this combined study focused on applying infrared (IR) inspection to T700 nozzle segments for the purpose of detecting blocked airfoil surface cooling holes and for the purpose of estimating cooling flow rate. Infrared inspection is based on computerized analysis of infrared thermal transient images of airfoil surfaces following a sudden injection of a cooling fluid into the airfoil. The practicality of detecting blocked surface holes was demonstrated on a very small number of parts, but the high signal-to-noise ratios obtained indicate that excellent blocked hole detection performance can be expected on larger samples of parts. The application of infrared inspection to predict airflow rates for 47 nozzle segments run twice each (94 runs total) yielded a root-mean-square prediction error of approximately 3.3% of the mean airflow rate. While this result does not meet current production accuracy requirements, several areas where the accuracy of infrared inspection can be improved are examined in this report (Figure 1).

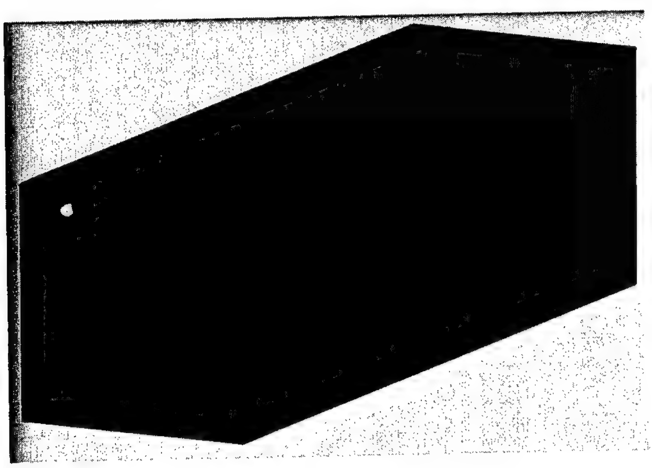


Figure 1

Current Practices

The primary intent of all inspection techniques here is to assure that the proper amount of cooling air will pass through the blade or vane during engine operation to avoid overheating and premature failure of the part, and to assure that the distribution of the cooling air is such that localized "hot spots" on the part will not be encountered. There are several primary inspection techniques presently employed. The first is light inspection. This involves inserting a small light source into the part and visually observing the presence of holes drilled through to the surface. When this is combined with a count of the holes, there is assurance that the part contains the proper number of holes and that they are open to the surface; but there is not other quantitative information available about these film cooling holes such as their size. Also, light inspections are relatively slow to perform and are greatly limited by the part configuration. In fact, many recent turbine blade and vane configurations are so complex that light inspection can only be used for certain holes on the part or not at all, either because light sources cannot be inserted or because the film cooling holes do not open to the surface along a straight line.

Another technique similar in nature to light inspection is precision pin inspection. This technique, however, is so slow and tedious that the holes can only be checked on a sampling basis. It does, however, provide some information regarding the hole diameters, to within the roundness and straightness of the hole, and can assure that the hole is open to the surface.

A third inspection technique used on all configurations is waterflow inspection. In this inspection, water is fed into the air feed holes and an inspector observes streams of water as they emerge from the film cooling holes. By so doing, the inspector can determine whether the hole is open to the surface or not. But this method does not necessarily detect partial incomplete removal of the casing core. Also, the spacing of the holes can be so close that the emerging streams quickly merge into a single sheet of water making for difficult identification of a single hole that is not flowing. A similar situation can also arise where the water streams emerge from one row of holes on the concave side of an airfoil and interfere with the water streams emerging from another row directly behind it.

A fourth inspection technique is airflow inspection. Here a specified air pressure is established across the cooling circuit. A measure is then made of the total mass of air that is flowing through the part. This may be done to the part as a whole or in several steps by sealing off certain combinations of holes and measuring the mass airflow through the remaining holes. Regardless, this technique is very labor intensive and suffers from the need for continued calibration of the equipment.

Infrared inspection performs the same functions as light, pin, waterflow, and airflow inspections and offers significant advantages over these current techniques.

The IR Inspection System

In the system used for this study (Figure 2), the refrigerant tank contained a saturated liquid/vapor mix of refrigerant R12 (dichlorodifluoromethane) at room temperature. The coolant reservoir provides a smooth delivery of coolant to the fixture, while the electronically controlled solenoid valve turns the coolant flow on and off. The flow control valve is a precision, calibrated variable orifice valve which meters coolant into the part. The part fixture is a modified production waterflow fixture which allows introduction of the coolant into the part and provides precise positioning of the part. The fixture is rigidly mounted to the lab bench and consists of two machined out aluminum blocks with precision molded urethane inserts.

A commercial scanning infrared camera with a cryogenically cooled Indium-Antimonide detector was used; it is sensitive to infrared radiation in the 3-5 micron range, has a field rate of 25 Hz, an effective spatial resolution of about 60 elements, and a thermal resolution of 0.2 degrees C. The synchronizing circuit is a special purpose electronic controller which only allows the solenoid valve to open when the infrared camera raster scan is positioned at the upper left corner of the field of view. This allows the raster scan of the camera to act as a precise clock which starts "ticking" when the solenoid opens. The camera positioning equipment consists of four calibrated manual positioners to allow three orthogonal axes of translation (x, y, and z) and one axis of rotation. The videoscan convertor consists of an analog to digital converter, a buffer memory, and a digital to analog converter. The purpose of the videoscan converter is to convert the output from the infrared camera to standard black and white televisiion video so that the data can be recorded with a videotape recorder. The infrared data is videotaped so that it can be played back a frame at a time because the thermal transient in the airfoils takes less than a second.

Advantages of Infrared Inspection

The openness of all surface cooling holes can be evaluated using infrared inspection, because no known current airfoil geometry presents significant difficulty for infrared blocked hole detection. Infrared inspection can localize the cause of abnormal total flow rates (e.g., several holes with reduced diameters) by analyzing the thermal patterns on the surface of the part corresponding to each cooling circuit, thus facilitating part rework when necessary. Also, partial blockages of internal passages in air cooled airfoils can be readily detected and localized with infrared inspection.

Infrared inspection also offers advantages of

- Improved productivity
- Improved sensitivity
- Improved accuracy
- Improved reliability (i.e., repeatability).

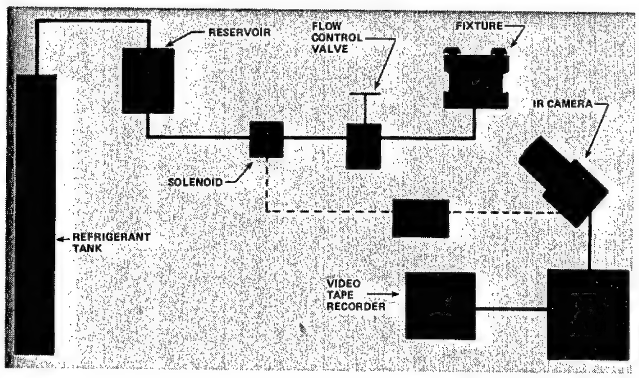


Figure 2

Recommendations

Although this study demonstrated (1) the practicality of using infrared inspection for blocked hole detection and (2) that airflow rates can be estimated using infrared inspection data, the accuracy required for acceptable airflow rate estimation has not been achieved. Improved accuracy may be obtained by making modifications in three areas: the heat transfer fluid, data acquisition, and heat transfer modeling. Refrigerant R12 was used as the

coolant in this study. The temperature of the laboratory was controlled, so the thermodynamic state (i.e., pressure and temperature) of the refrigerant was controlled as well. However, the temperature and pressure of the refrigerant were not variable in the feasibility and application studies (and cannot be controlled independently), so optimum inspection conditions could not be obtained. In addition, the pressure at the part was reduced to a suitable level by a flow control valve. This unfortunately served to reduce the sensitivity of the infrared inspection process, since the thermodynamic state of the refrigerant at the entrance to the part varied with the total flow. Finally, the possible environmental impact considerations associated with release of this material into the atmosphere pose difficult problems. Therefore, a gas (probably air) should be used as the heat transfer fluid in the future. This will allow for independent control of both the temperature and pressure of the coolant fluid at the entrance to the part so that optimum test conditions can be achieved.

In this study, specific infrared inspection variables were chosen to be measured because they were expected to be related to airflow rate. The tacit assumption was made that these variables were linearly related to airflow rate and that the unknown parameters in the linear relationships could be determined by (straight line) linear regression analysis. This is a very reasonable approach, but if a higher order parametric model of the airflow rate vs infrared measurements could be developed, then linear regression analysis could be used to determine the unknown parameters in the model and more accurate predictions over a wider range of airflow values could be expected. In addition, the number of experimental observations required to obtain a given prediction accuracy decreases as the theoretical model approaches the true physical situation.

Finally, and most importantly, theoretical analysis may well lead to inspection criteria for air cooled blades and vanes which are given in terms of infrared variables rather than in terms of airflow rates. This will greatly reduce the time required to develop an inspection procedure for new parts as they are designed.

Automated Optical Area Measurement

Turbine nozzle exit areas are currently evaluated by one or both of two totally different measurement schemes. The first, and most widely used method, utilizes a multi-probed, manually inserted mechanical gage which samples the passage dimensions at a few fixed locations. The second technique is based upon the analysis of flow and pressure relationships observed as air is forced through the nozzle passages under closely controlled conditions.

Neither of these approaches directly measures the true exit area. The mechanical gage does not factor in corner radii or irregularities on the passage perimeter, and the airflow analysis yields a calculated effective area and flow function. However, the values obtained by these techniques correlate, in varying degrees, to engine performance.

These traditional methods yield acceptable results when applied to nozzles incorporating relatively large passages and having sizeable tolerances. Repeatability/accuracy becomes marginal, however, when the passages are as small and the tolerances as tight as are encountered in the T700 Stage 1 nozzle. Airfoils incorporating a notched trailing edge design, as in the T700 Stage 1 nozzle, serve to further compound the problem.

This image analysis technique, which was a joint effort between General Electric and Bausch and Lomb Analytical Systems Division, provides a direct, noncontact measurement of the observed passage area and is amenable to computer control. Variations in passage size and shape and perimeter irregularities are automatically accommodated with no effect upon accuracy and repeatability. Repeatability, expressed as a percentage of the observed area, appears to be markedly better than that obtainable with other methods when applied to the measurement of T700 Stage 1 nozzle area.

System Concept and Operation

The feasibility model was based on the use of Bausch & Lomb's recently introduced precision Instrument Scanner Model IS-3, developed specifically for image analysis applications (Figure 3). This approach to nozzle inspection (using an IS-3 scanner, a light curtain to define the orifice, and a swinging mirror to facilitate measuring the orifice in two sections separated by a digital frame line) proved to be eminently successful. While this method does require rectification of the second (outer) section of the orifice image, the procedure—although rigorous—is not particularly time consuming.

Note: Oblique viewing of the outer section causes distortion of the image. Rectification is the mathematical adjustment of the stored data to make it representative of the true size and shape.

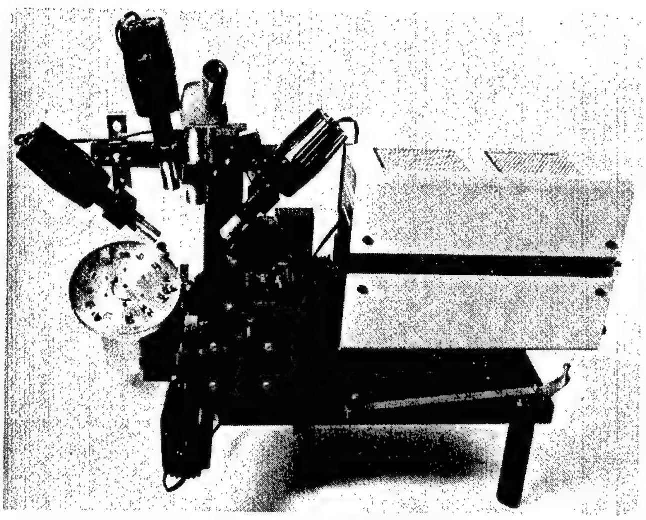


Figure 3

The measurement regime used is to average ten consecutive images of the inner half of each orifice bounded by the inner band, upper and lower airfoils and the digital frame, then switch the mirror to the other position while automatically swinging the lens back to the proper angle and position to fulfill both the focus condition and the Scheimpflug condition. Then the computer switches to a new digital frame, tangent to the previous frame on the side toward the rotor centerline; averages ten areas bounded by the digital frame, upper and lower airfoils and outer band; measures an eleventh area; computes the deviation from the average of the previous ten; rectifies the eleventh area; and corrects the rectified area to represent the average of the ten. Since rectification requires a line-by-line mapping of the image, it is too time consuming to average the rectified areas.

With the present setup, using more operator interaction than would be used in a production fixture and with none of the mechanical motions under computer control, it was possible to inspect a nozzle assembly in about 40-45 minutes. Given computer control of mirror and rotor position, which requires less operator interaction, the nozzle assembly should be measurable in less than 30 minutes, floor to floor. Further refinements in programming and/or a faster computer could lower this time by as much as 30%, if that is necessary. Some operator interaction in setting thresholds seems advisable, but does not seem to require great skill. It is probable that the operator should monitor the images to see that no gross defects slip by—it is a good opportunity to observe the orifices at an effective magnification of about 20X.

The fixture was connected to a standard Omnicom FAS-II system for automatic measurement of the nozzle images. A special software program was generated to control the acquisition of the images, the measurement routines, the rectification process, and reporting of the results.

Conclusions

Measureable improvement in repeatability is probably possible with this system, although it may incure a loss of measuring speed. For an individual passage measurement, the System 2 sigma repeatability (with 95% confidence) is $\pm 0.24\%$ of the observed area. This equates to ± 0.0004 sq. in. for a nominal exit area of 0.1549 sq. in. Also, the total area of T700 Stage 1 nozzle, a summation of twenty-four passage measurements, can be determined with a 2 sigma repeatability (with 95% confidence) of $\pm 0.05\%$ of the observed area. This is ± 0.0019 sq. in. for a nominally sized nozzle with a total exit area of 3.7185 sq. in.

Since this is a comparative measurement system, accuracy is dependent upon proper calibration to a known area standard. Repeatability type errors inherent in the calibration process may be reduced to an insignificant level by averaging several measurements of the standard area.

In addition, it was found that lighting is critical. Further development is needed to reduce the influence of illumination variations upon the definition of the observed area. Also, the nozzle fixturing must provide a means to rapidly adjust the viewing angle to accommodate variations in airfoil angle and to compensate for the effect of airfoil trailing edge cutback upon the positions of the exit area planes.

Experience with the manually operated demonstrater system indicates that, with minor modifications, an inspection rate of three nozzle assemblies per hour would be feasible. A fully automated system with improved computer programming should prove slightly faster. This system displays an excellent magnified image of each passage as it is measured. It also is capable of storing and comparing images. These features could prove useful for evaluating nozzle quality and symmetry.

Greater Reliability Possible

Beam Lead Device Costs Reduced

Complexities in the processing of beam lead devices were determined that led to important guidelines relating to the fabrication of these items during a manufacturing technology program sponsored by the U.S. Army Electronics Command. Carried out by Motorola for ECOM, this program originally was designed to refine fabrication of both discrete and integrated circuit beam lead devices for large scale production.

It was also expected that—through improvements in manufacturing techniques and subsequent yields—the cost of beam lead devices could be significantly reduced and become more attractive for widespread military use. If successful in lowering costs, it was believed that commercial hybrid manufacturers would also find these devices to be more attractive. The improved reliability of beam lead devices compared with standard chip and wire devices had long been established.

Discrete Devices Offer Challenge

Soon after some of the discrete device batches had been processed, it became evident that they offered a stiff challenge to the program. Each discrete device is unique in its processing requirements—from a processing standpoint, each must be targeted for selection from what would normally be a family of devices in a normal chip and wire production line. Any variation in diffusion times, temperatures, or other processing variables on any of the devices meant that the specific type might have a low yield; similarly, some other device in the family might produce quite a high yield. Furthermore, this can occur even on the same wafer.

The same starting material and processing procedures cannot be employed in the production of beam lead devices as in chip and wire devices. Parameters change drastically when processing with beam lead technology, making it difficult if not impossible to consistently meet the device specifications. A typical cross section of a transistor serves to illustrate the continuous problems faced in processing discrete devices with beam leads (Figure 1). A top collector contact is needed instead of a standard bottom collector contact on non-beam lead devices. Probably the most critical step is in the collector diffusion. It is during this long interval that excessive diffusion of the substrate occurs, and this changes the device characteristics quite dramatically.

Motorola was not completely successful in achieving the program's goal of a 20 percent yield on any of the discrete devices. Quite possibly, some of them could and would have met or even exceeded this goal, but this would have been as much through chance as through rigid process control. Although the results were disappointing, a lesson certainly was learned—it is not practical to expect to consistently achieve high yields on a specific beam lead discrete device from a family of devices.

JAMES F. KELLY is a Project Engineer at the U.S. Army Communications Research and Development Command, where he is involved with production engineering and MM&T programs. During his past five years with CORADCOM and his previous eleven years with ECOM, Mr. Kelley worked on the automation of GaAs diode fabrication, automating the optical inspection of PC boards and hybrid substrates, development of pulsed IMPATT diodes, and the online testing and adjustment of electronic assemblies in addition to many other projects. After receiving his B.S. in Electrical Engineering from Pennsylvania State University in 1953, he pursued graduate studies there and at the City College of New York. He also worked at the Army's Tobyhanna Depot in Pennsylvania until 1964.

Photograph

Unavailable

Schottky Process Implemented

The original design/process used for the production of integrated circuits employed gold doping to reduce lifetime, whereas Motorola elected to design with Schottky devices in mind. The first two yield lots failed to produce

NOTE: This manufacturing technology project that was conducted by Motorola was funded by the U.S. Army Electronics Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ECOM Point of Contact for more information is Mr. James F. Kelly, (201) 532-4958.

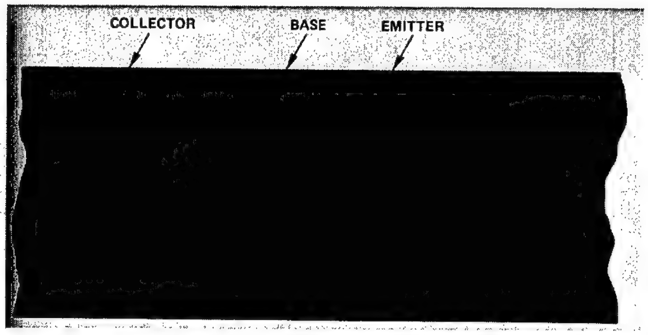


Figure 1

any viable circuits due to metallization shorts. Since the chip size had already been established, the metal line widths and spacings had to be limited to fit all of the circuitry on the chip. This resulted in the metal problems which caused the zero yields. However, this problem was corrected by the third batch.

The original design size proved to be inadquate due to the higher offset voltage of the Schottky devices. The Schottky devices are faster than conventional gold doped devices because no minority carrier injection ever occurs at the collector base junction. Therefore, no stored charge can ever accumulate in the collector region and slow down turn off time. Excess base drive is shunted away from injection and flows externally through the Schottky diode.

Master Masking Initiated

The master mask concept is a manufacturing technique that provides precision alignment, reduced device geometries, and a process relatively free from pin holes. This concept was implemented in the production of the beam lead integrated circuits in the Federal High Reliability Products Operation for the first time in this program. Essentially, the master mask is a layer of silicon nitride deposited on the initial oxide grown on the starting material. The reason for the pin hole protection should be evident—it would be necessary to have coincidence in pin holes in a precise location in both the nitride and the oxide for diffusion or metallization shorting problems to occur later.

For simplicity (Figure 2), several processing steps have been combined. First, the base and resistor diffusions

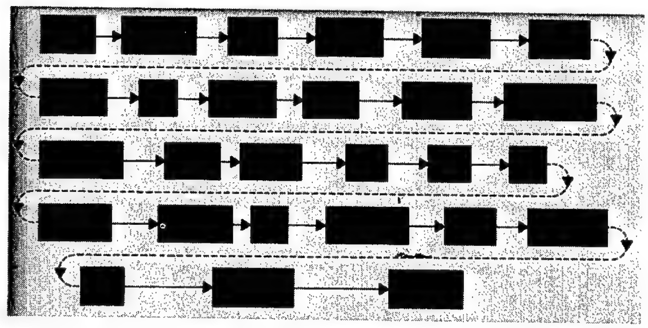


Figure 3

have been completed, followed by the emitter diffusion. The latter is the only diffusion mask which requires critical alignment, since it is not associated with the nitride master mask. This figure represents the final step prior to metallization. A flow chart summarizes the entire operation (Figure 3).

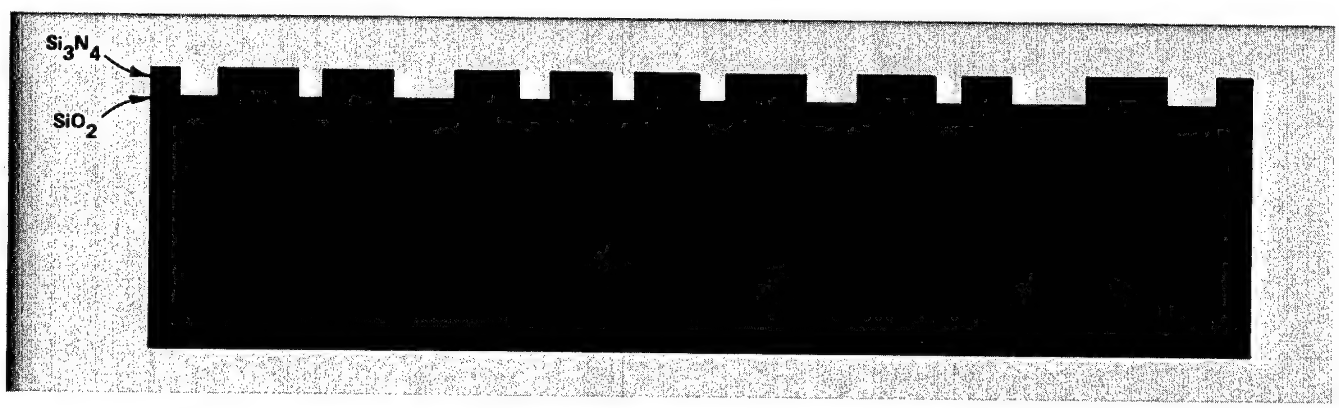


Figure 2

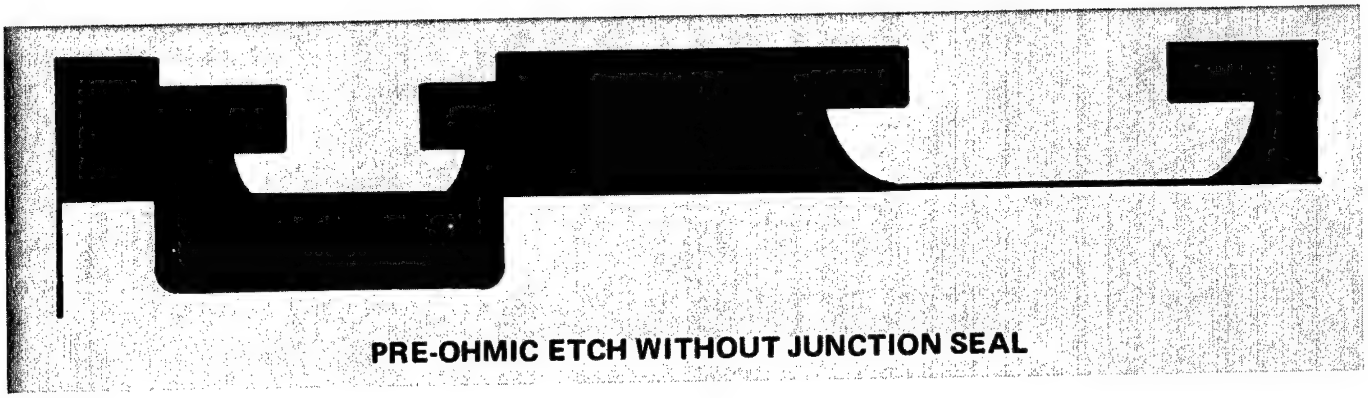


Figure 4

Modified Seal Junction Improves Yields

Another processing improvement developed earlier which improved the yields for beam lead devices was in the sealed junction. A sealed junction means that all of the PN junctions are protected from the deleterious effects of charged ions such as sodium. There is a difference in the thickness of the oxide at the point where it has been etched from the preohmic vias (Figure 4). This condition can result either in under etching, where a marginal or no preohmic metal will result, or in over etching, which can result in an undercut that can shadow the deposited metal or, in some cases, uncover PN junctions under the nitride lip.

To overcome this problem, a modified sealed junction was developed. The original master mask nitride is removed and the oxide is etched from the areas where metal contact is to be made prior to nitride deposition. Next, a thin layer of oxide is regrown in these areas; this allows subsequent etching to be uniform across the wafer, thus eliminating any voids in the platinum deposition which follows. (Figure #5 shows the results of the completed sealed junction process.)

Program Sees Early Results

Although there were some disappointments during this program, especially with the discrete devices, in the final analysis there were more positive results than negative. Specifically, processes and controls were established on the integrated circuits after only some twenty lots of material had been processed. And yields were significantly higher than first though possible.

Although significant marketing research indicated a need for these devices, the requirements for beam lead devices all but disappeared. However, much was still learned from this program, which has provided Motorola with technical experience in areas not previously attempted. Further, some of the technology advances were adopted by other production groups at Motorola, thereby enhancing their capabilities and yields.

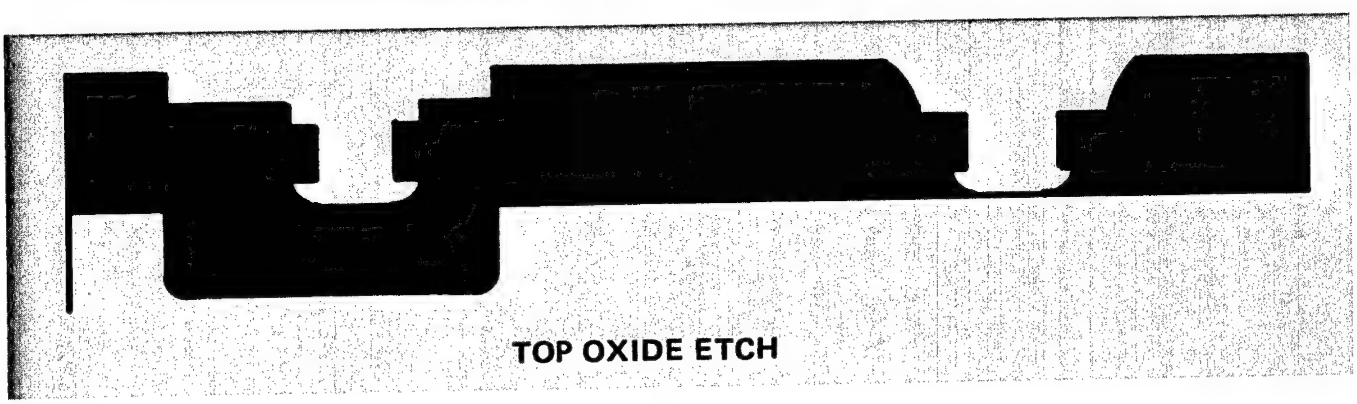


Figure 5

HERF Affords Savings

Pneumatic Mechanical High Energy Forging

JOHN JUGENHEIMER currently is Project Officer managing the design and installation of a chemically bonded sand molding system at Rock Island Arsenal. As an Industrial Engineer for the Industrial Facilities Planning Branch at the Arsenal, he also manages a program to rebuild or replace the fifty-four overhead cranes used at the facility. Prior to these tasks, he led projects on high energy forging (see accompanying article), inertial welding, fine blanking of small caliber weapon parts, and automated rotary forging of small caliber gun barrels. He has worked at Rock Island Arsenal since receiving his B.S. in Engineering Operations in 1965 and his M.B.A. in 1966.

The U.S. Army is always looking for ways of reducing the costs associated with the production of hardware items, and such was the outcome of a joint project sponsored by Rock Island Arsenal and conducted by Precision Forge Division of the Whittaker Corporation. Because forgings are heavily used in the production of such end items as combat vehicle gun mounts, artillery, small arms, and aircraft weapons, a new pneumatic/mechanical forging process—High Energy Rate Forging (HERF)—was studied to determine if it had the potential to produce such end items.

Once such potential was determined, then a contract was let to Precision Forge to purchase a Model 1220-D Dynapak HERF Machine (Figure 1). The machine and its supporting power unit and control console then were installed at Rock Island Arsenal. Subsequently, an operator was trained on the HERF equipment and a tooling engineer received instruction on the design and manufacture of HERF dies at the Dynapak plant.

A Good Process, But Limited

The following conclusions were based on work performed during this project:

(1) The HERF process is not as flexible as a steam hammer. However, for appropriate shapes and metal displacements, the HERF process will form forgings that are not possible on conventional forging equipment. On symmetrical parts with large metal displacements, the HERF process allows the forming of deep extrusions or large height to diameter ratio upsets. HER forgings can be formed in one forging blow to closer tolerances, and with little or no waste in the form of flash. Due to this and the ability to utilize smaller draft angles, HER forgings generally require less finish machining.

(2) Unsymmetrical parts, or parts where there is little metal movement, are not good HERF applications, as the die life is shortened due to high die load levels under these conditions.

(3) A standard die material such as Finkl DURO DI, Temper 2, is suitable for HERF dies which are not heavily loaded or for the body portion of the die, which is moderately heavily loaded. For HERF die punches or heavily loaded die bodies, a material with better properties is required. Heppenstall, Special C, Temper AA, was found to be quite good in heavy die loading situations.

(4) In general, HERF dies may be designed to produce forgings to closer tolerances and with less draft than conventional forgings. Draft angles used on HERF dies in this project ranged from 0 to 3

NOTE: This manufacturing technology project that was conducted by Whittaker Corporation was funded by the U.S. Army Armament Materiel Readiness Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRCOM Point of Contact for more information is Mr. John Jugenheimer, (309) 794-4135.

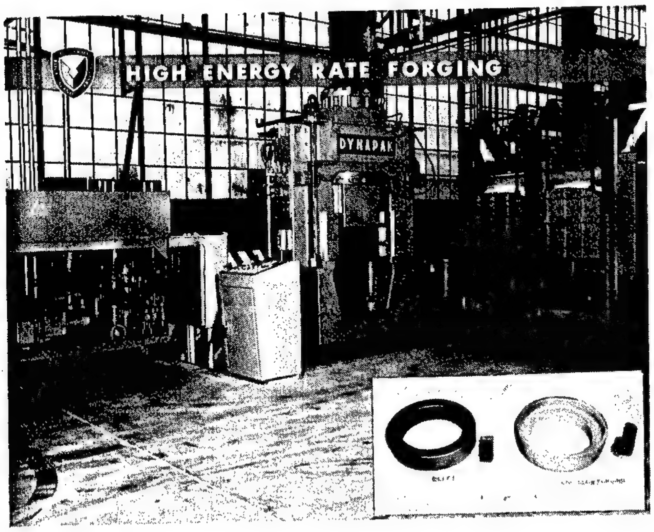


Figure 1

degrees. Conventional draft angles are about 7 degrees. Sharp corners and small radii should be avoided on HERF dies. Generous radii lower stress concentrations and will fill the forging with lower forging pressures.

(5) No metallurgical problems were observed in the production of HER forgings.

Machine Specifications

The Dynapak 1220-D HERF machine used in this study has the following specifications:

Rated Energy	225,000 foot-pounds
Rated Stroke	15 inches
Maximum Stroke	20 inches
Maximum Operating Pressure	2000 p.s.i.
Open Height	41½ inches
Die Space	24 x 22 inches
Cycles Per Minute at Rated Stroke	8
Ejector Capacity (Lower)	18 tons
Ejector Stroke (Lower)	9 inches
Ejector Capacity (Upper)	18 tons
Ejector Stroke (Upper)	6 inches
Height Above Floor	140 inches
Depth Below Floor	45 inches
Length (Left to Right)	78 inches
Width (Front to Back)	28 inches
Weight	38,700 pounds
Hydraulic Power Unit	
Main Motor	150 h.p.
Ejector Motor	20 h.p.
Filler Motor	2 h.p.
Power Requirements	220/440 volt, 3 phase, 60 cycle
Hydraulic Fluid	(Petroleum Base) 80 gals. Houghto-Safe 1120 or Cellulube 200
Height	78 inches
Length (Left to Right)	113 inches
Width (Front to Back)	52 inches
Weight	6565 pounds
Control Console	
Control Circuit	110 volt, 60 cycle
Height	50 inches
Length	24 inches
Width	23 inches
Weight	200 pounds
Total Shipping Weight	47,700 pounds

HERF Fabrication Begins

The first component selected for fabrication on the HERF equipment was a collar (Part No. 11578376, How. M185). The forging stock was a 4140 steel rolled ring 10⅜ inches OD x 7⅝ inches ID x 2¼ inches high. The stock was heated to 2000 F and forged at a fire pressure of 1975 lb. This fire pressure is near the maximum limit of the equipment. The forging was successfully formed in one forging blow which displaced (back extruded) approximately 31 cubic inches of steel.

The use of the HERF process on this component resulted in the use of less forging stock and reduced machining time for finishing. The die for this component was fabricated from Heppenstall Pyrotem, Temper A, Grade 6357 die steel. The die performed satisfactorily and remains in serviceable condition.

The second component to be forged was a recoil body (Part No. 7148066, 155MM). The forging stock was 1045 steel 4¾ inches in diameter x 2-1/16 inches high. The stock was heated to 2000 F and forged at a fire pressure of 1100 lb. The forging was successfully filled in one forging blow which back extruded approximately 18 cubic inches of steel. The forging produced is straight sided on the OD, with only three degrees draft on the ID. This configuration is not feasible on conventional drop hammer forging.

Again, the use of a HER forging resulted in using less material to produce a forging which subsequently required less finish machining.

The die material used was Heppenstall, Special C, Temper AA. This material has good toughness and heat resistance at high hardness levels. These properties were demonstrated in the forming of the above component. Although the die was subjected to high temperatures and heavy shock loadings, no die problems were experienced. The die remained in good condition and still is serviceable.

The HERF equipment also was used to fabricate a variety of nine different forgings for the Bridge Launcher M60A1. Approximately 950 forgings were produced. In an effort to reduce die costs, a less expensive die material was used for these nine dies. The die material, Finkl

Duro I, Temper 2, did not have satisfactory properties for use as the punch portion of a highly loaded die set.

One of the above mentioned parts was examined as part of the project. A land ring (Part No. C13211E3188) represented an upset type forging. The forging stock is 4340 steel 2½ inches in diameter x 3⅞ inches high. The stock was heated to 2200 F and forged at a fire pressure of 400 lb. The forging was successfully upset with one forging blow which displaced approximately 10 cubic inches of steel. The die for this component was fabricated from Finkl DURO DI, Temper 2. The die was very easy to produce because it had a shallow cavity with no ejector. In this application, the less expensive die material performed very well, and the die remained serviceable.

To evaluate the HERF technique on the forging of aluminum, the land ring die and the body die were used to forge respective parts from aluminum stock. Both components were successfully formed in one forging blow. As would be expected, the forgings were produced with lower fire pressures and less difficulty than the steel parts.

Savings in Both Tooling and Production

The collar, which was the first attempt at HERF fabrication, presently is produced using the conventional hammer forging technique. Tooling costs totaled $3750 using this technique—$1350 for the die material and $2400 for die sinking. Using the HERF process, these costs were reduced to $412 and $2000, respectively, for a total tooling cost of $2415—a net savings of $1335. Forging costs (which included stock, forging, and rough machining) were similarly reduced, from $12.20 per piece using hammer forging to $9.07 for HER forging—a savings of $3.13 per piece.

For the recoil body, which is presently machined from solid stock, the cost per piece was reduced from $18.48 to $4.27—a reduction of $14.21 per piece.

For a sample of five dies used on the Bridge Launcher forgings, a tool engineering estimate of the cost to produce the same die for a drop hammer forging was obtained. Generally, HERF dies are less expensive to produce because they require less material and are easier to machine than a drop die.

By using the HERF process, an average savings of $1365 per die set resulted.

Metallurgical Evaluation

A potential problem that is indicated in HER forging is the generation of hot tears and/or eutectic melting caused by the rapid deformation of the forging. Sample forgings of the body and the land ring forged from both steel and aluminum were evaluated to determine if there was a problem in this area.

Examination of macroetched cross sections from the five high energy forging samples did not reveal hot tears or ruptures in the hot worked surfaces. Figures 2 through 6 display the patterns of grain flow in the forged shapes for 6061 aluminum alloy and 1045 steel.

Microstructure surveys were conducted on the thick and thin sections of each forging. Eutectic melting at the grain boundaries was not observed in any of the samples.

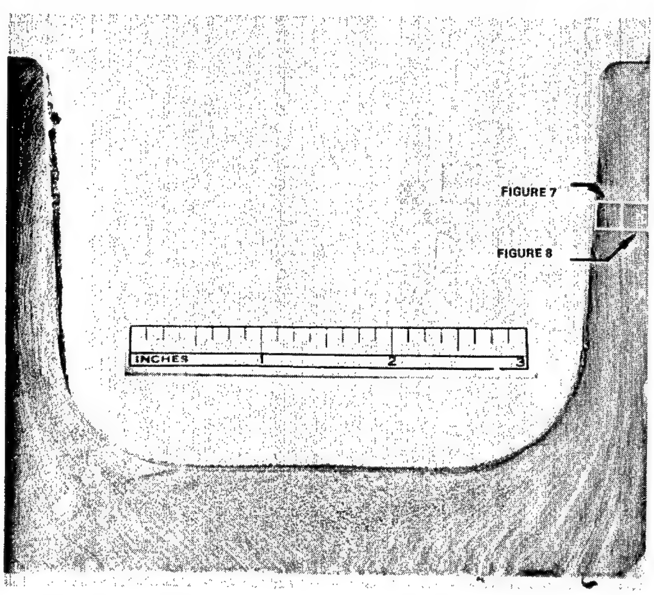


Figure 2

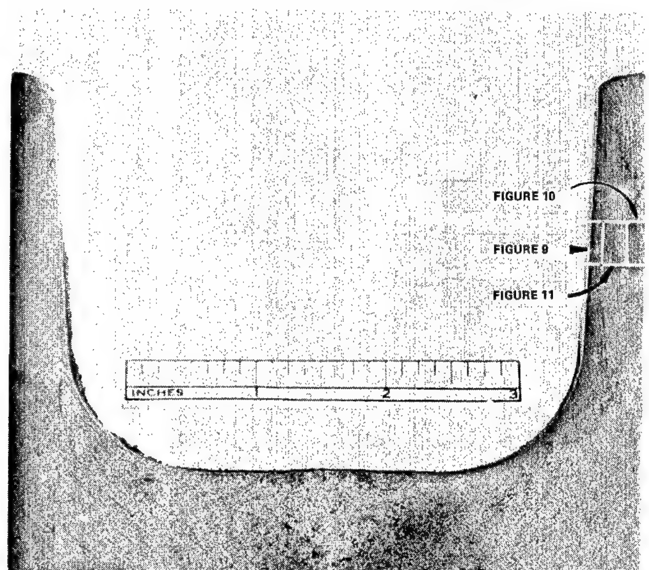


Figure 3

Figures 7 and 8 show cross sections of the ID and OD of the thin wall portion of aluminum Sample No. 1 (Figure 2

locates the cross sections). The large black particles prominent throughout the matrix of the thick and thin wall sections are magnesium-silicon. These particles are unusually large. When the particle size is very small, this phase is the strengthening constituent that precipitates finely after solution heat treatment and artificial aging. These extremely coarse particles, however, weaken the structure similar to overaging. Prolonged heat treatment of unforged samples at 800 F, the soaking temperature before forging, did not reproduce the coarse particle size found in Sample No. 1. Re-solution treatment in the laboratory, however, eliminated this embrittlement phase and no adverse effects are anticipated, even though the cause of the large particles was not isolated. Coarse particles were not found in aluminum Sample No. 2.

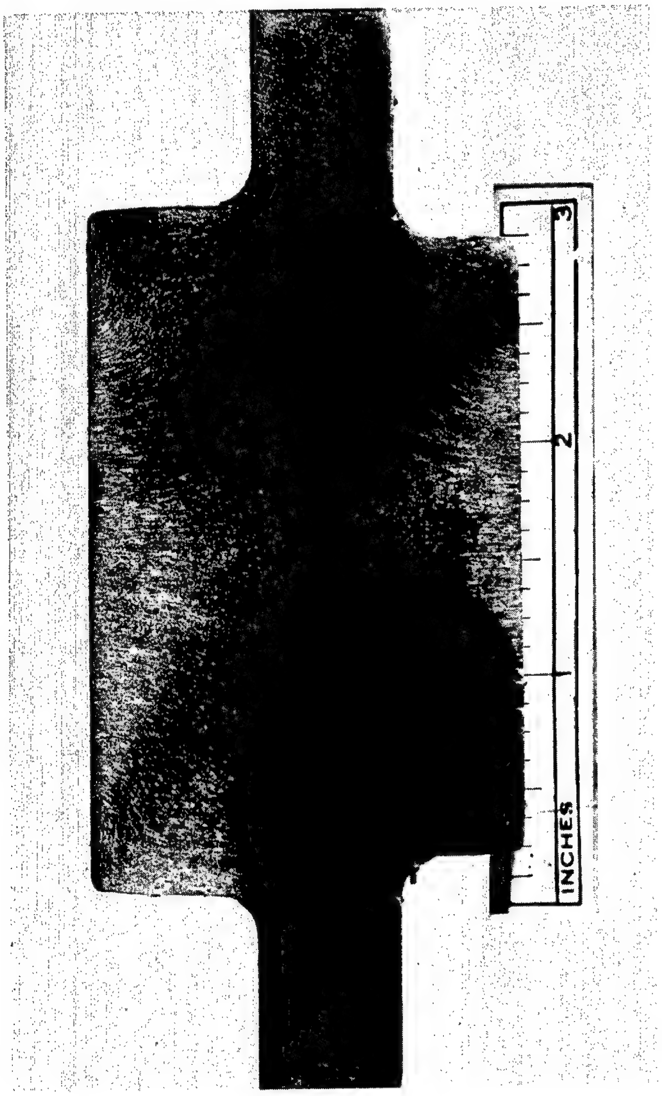


Figure 4

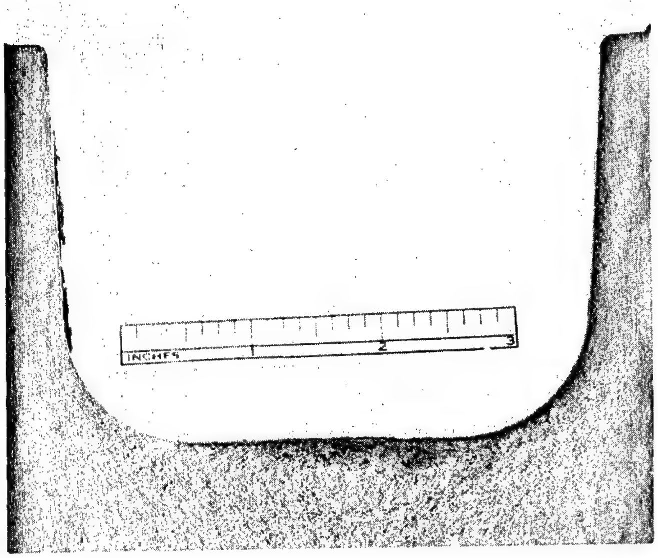


Figure 5

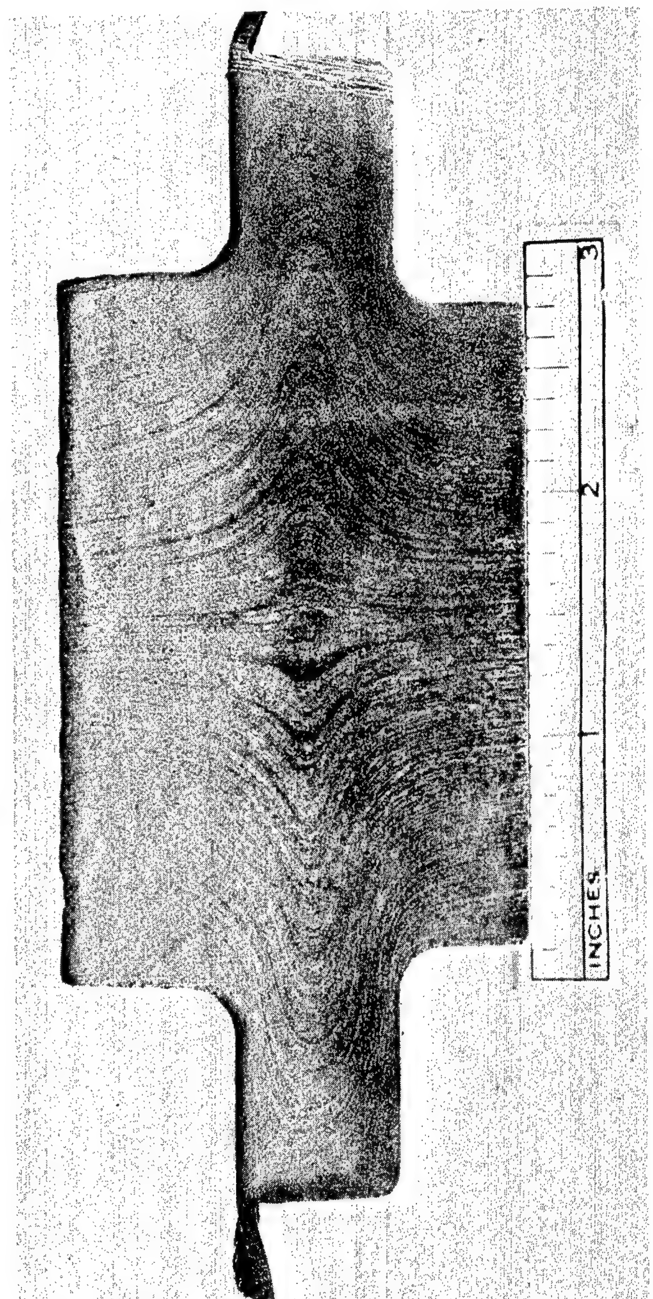


Figure 6

Sulfide inclusions appear only occasionally in the grain boundaries of the steel samples, therefore would not cause tearing at the forging temperatures. Figures 9, 10, and 11 show microsections of the 1045 steel in the thin wall, most hot worked portions of Sample No. 3 (Figure 4 locates the microsections). Decarburization appears only along the forged surfaces and is more extensive on the OD, or bottom die side. Finer grain structure also shows in the severely worked areas. Compare the grain sizes in Figure 9 and 10 with those in Figure 11, which displays the coarse, least distorted grains. The structures shown in the photomicrographs of Sample No. 3 are exemplary of the thick and thin sections in each of the steel forgings. Therefore, laboratory results indicated there was no detrimental metallurgical properties caused by HERF.

This new method of high energy rate forging will not replace conventional forging methods in every case. But in many instances it can offer lower cost and the ability to produce configurations that are not currently feasible by conventional forging methods. HERF's application will become more pronounced in the future.

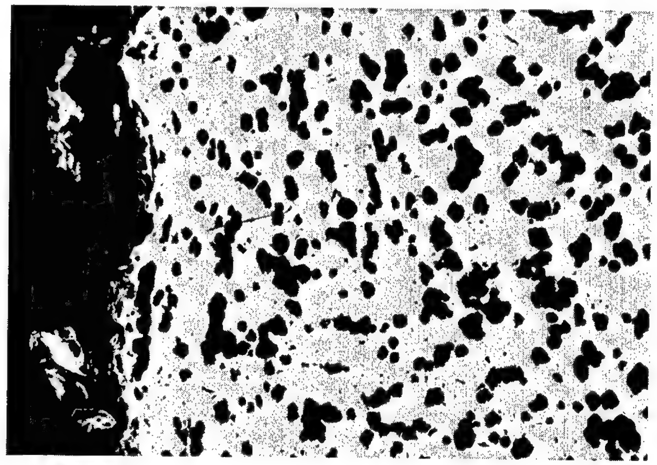


Figure 7

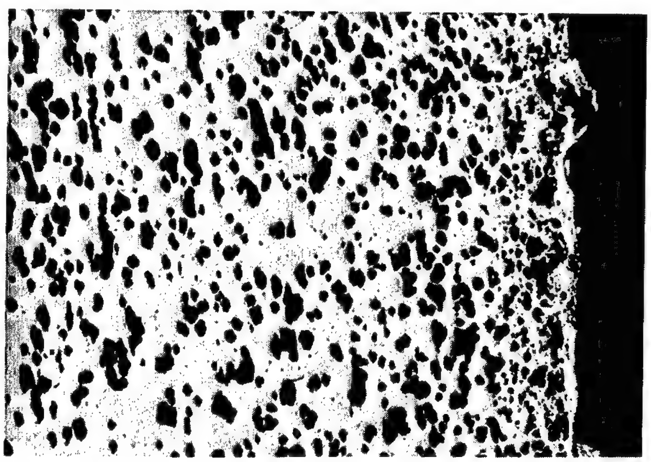


Figure 8

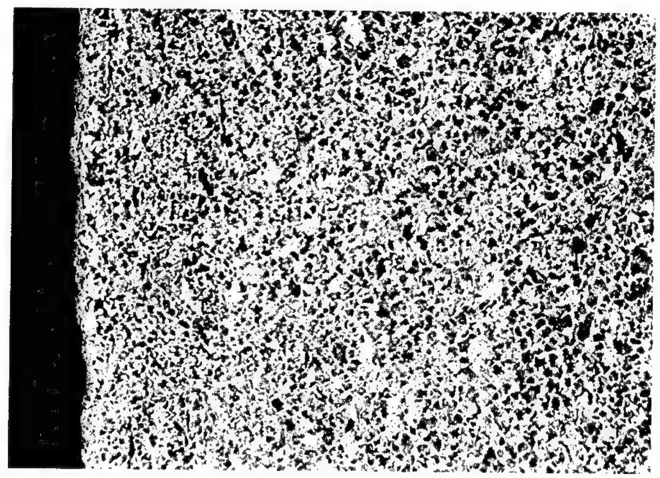


Figure 9

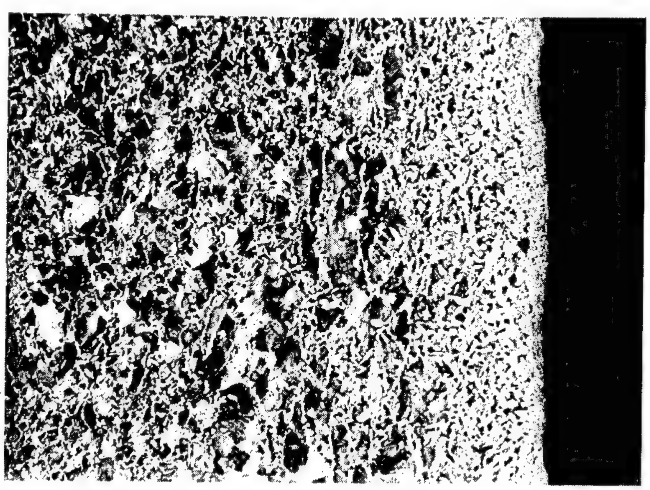


Figure 10

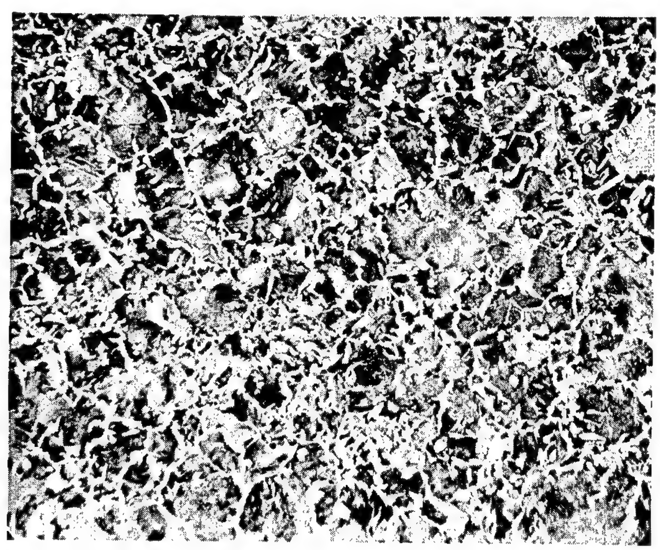


Figure 11

Compact, Rugged Telemetry Transmitter

Quantity Production Feasible

Artillery telemetry now is one whole level of efficiency higher following the development of a new compact, rugged crystal controlled L-band transmitter by the U.S. Army Materiel Readiness Command. This in-house project was undertaken to develop a telemetry transmitter that would function effectively in every current size of artillery round.

The recognized need by the U.S. Army for an improved artillery telemetry transmitter prompted development of such an item by the Harry Diamond Laboratories. A compact 1510 MHz transmitter having an efficiency of 6 percent at an output power level of 160 mW was produced. Physical dimensions are such that the transmitter can be readily potted in any artillery telemetry housing currently in use.

The Need

Information concerning the environments encountered by artillery projectiles immediately following gun launch is of prime importance to the designers of fuzes and fuze components. To acquire the signal from a telemeter early in its flight, its frequency must be maintained within a narrow passband; frequency shifts, which can be induced by shock, must therefore be minimized.

UHF transmitters are extremely sensitive to physical deformation, which can cause a small change in reactance that can—in turn—cause an appreciable change in frequency. Implementing the Department of Army directive to convert telemetry equipment from VHF to UHF required considerable in-house and contractual effort to develop ruggedized components for application in the 1435 to 1535 MHz telemetry band. One result was development at HDL of a high shock crystal and associated circuitry. A gun rugged step recovery diode (SRD) capable of high order harmonic generation was developed under an HDL contract by Hewlett-Packard Associates (HPA). Both of these components have survived tests at shock levels up to 70,000 g, a level judged sufficient for almost any artillery application.

The need remained for compact, efficient UHF circuitry that could be potted in artillery telemetry housings with the accessory hardware currently employed at VHF. The development of a prototype L-band transmitter was undertaken to fulfill this need.

F. THOMAS LISS is a Project Engineer at the U.S. Army Materiel Command's Harry Diamond Laboratories, where he has worked for the past 28 years following 5 years as a Philco Technical Representative. Earlier, he received his B.S. in Electrical Engineering from George Washington University. His primary activity currently is in the field of fuze systems. A Registered Professional Engineer in the District of Columbia, he has served as Chairman of the Instrumentation and Measurement Group of IEEE.

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The Whole and Its Parts

The transmitter (Figures 1 and 2) contains four interconnected 1½ inch diameter modules. Components for the modulator, crysal oscillator, and 75 MHz power amplifier were mounted on a single 1½ inch diameter printed circuit board. The multiplier, filter, and 1.5 GHz amplifier sections were assembled on three separate boards. Stripline circuitry was employed to confine the field of the region between ground planes and thereby reduce the detuning effects caused by subsequent encapsulation. Input and output impedances were kept at 50 ohms to facilitate electrical testing of the individual modules and to allow the transmitter to be assembled with minimum redesign.

In the schematic diagram (Figure 3) transistors Q1, Q2, and Q3 are the modulator, crystal oscillator, and power amplifier stages, respectively. The quartz crystal, which is located in the center of the board, was developed by HDL to withstand gun launched accelerations up to 70,000 g.

NOTE: This manufacturing technology project that was conducted by Harry Diamond Laboratories was funded by the U.S. Army Materiel Readiness Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The HDL Point of Contact for more information is Mr. Tom Liss, (202) 394-2410.

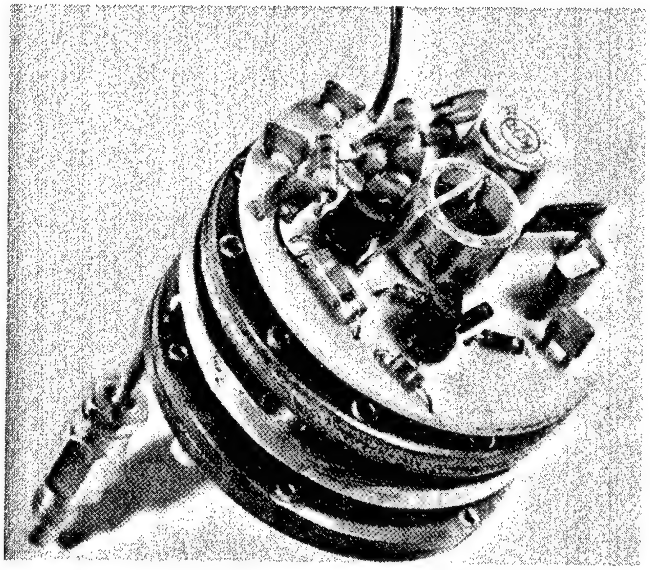

Figure 1

Modified Colpitts Oscillator

The crystal oscillator is a modified Colpitts type utilizing a 2N2553 transistor in a common base configuration. Temperature tests over a -40 to 90 C range indicate that a frequency stability of 0.002 percent can be obtained with oscillators of this type.

In telemetry applications, the transmitter is modulated by a subcarrier oscillator (SCO) whose frequency is modulated by transducer data. The SCO output is applied to transistor Q1 and appears across capacitor C3, which also serves as an RF ground for the base of the crystal oscillator. Measurements of the resulting spectrum at 1.5 GHz showed a phase modulation sensitivity of 13.1 radians/volt.

In phase modulation, the frequency deviation is directly proportional to the modulating frequency, so higher SCO output voltages are required at lower subcarrier frequencies. With a 70 kHz subcarrier, a r.m.s. output voltage of 136 mV is required to obtain a deviation of ±125 kHz. Using a 165 kHz subcarrier, the same deviation can be obtained with a 58 mV output.

Step Recovery Diode Multiplier Used

Since it was desirable to minimize the number of tuned circuits and tuning adjustments to facilitate the encapsulation procedure, a single step recovery diode (SRD) was employed to provide a frequency multiplication of twenty. A detailed analysis of the input impedance of an SRD multiplier was performed by Hewlett-Packard Associates under an HDL contract. This analysis showed that the input impedance of a network consisting of the drive inductance L and SRD can be represented by a parallel equivalent impedance containing an inductive reactance in parallel with a resistance. Here, a capacitor resonates with the equivalent inductive component of the input impedance at the input frequency and provides a low impedance path for most of the spectral components of the diode generated pulse. The equivalent resistive component is then matched to the 50 ohm source impedance by means of a matching network. A choke provides RF isolation for the self bias resistor, while another coupling capacitor provides dc isolation from the source.

Unlike a conventional diode, the conduction angle of an SRD is very large since charge stored in the diode during the forward current portion of the cycle maintains the diode in the conducting state over a major portion of the

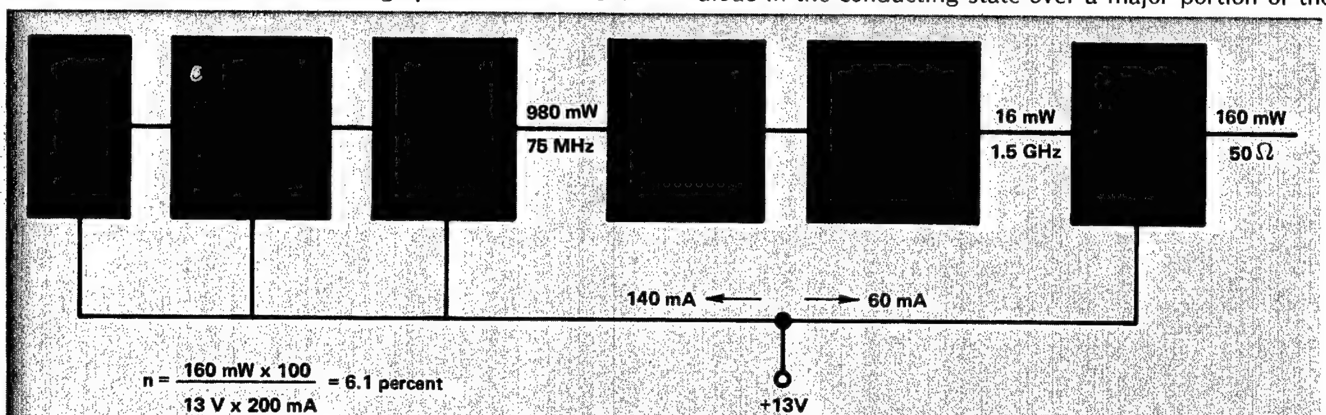

Figure 2

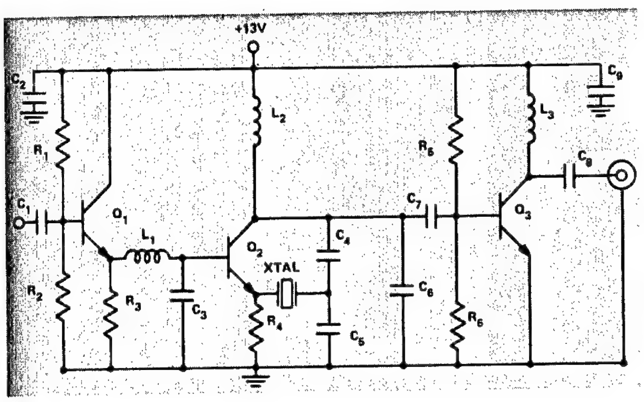

Figure 3

reverse current cycle. Near the end of the reverse current cycle, the stored charge is depleted and at this instant, the diode becomes an uncharged capacitor. Energy stored in the field of the drive inductance L is then transferred to the capacitor, and the exchange of energy that follows would produce the typical ringing waveform of an RLC circuit if the diode remained in its off state. Since the second half cycle of the transient drives the diode into conduction, the resonant action is destroyed, and a single pulse having a width approximately equal to one half the period of the output frequency is produced once each input cycle.

The diode generated pulse enters the output line, where it undergoes multiple reflections from the output and diode ends of the line. Reflections at the output end occur without phase reversal, while those at the diode or shorted end occur with phase reversal. Since the pulse traverses a distance of one half a wavelength between output reflections and returns each time with its phase reversed, a damped waveform appears at the output.

The output capacitor was experimentally adjusted while the line length was appropriately foreshortened until the maximum amplitude in the damped output spectrum appeared at the 20th harmonic of the input frequency. In this state the damped waveform could be filtered to obtain a CW output with little loss due to rejected sideband energy.

Interdigital Filter

Undesired harmonics of the 75 MHz fundamental are attenuated at the multiplier output by a five element interdigital filter having a center frequency of 1.5 GHz, a fractional bandwidth of 5 percent, and a temperature coefficient of 185 kHz/degree C. With this form factor, the amplitude of the closest 75 MHz harmonic was 45 dB below the 1.5 GHz carrier.

The measured filter insertion loss was 5 dB as predicted from L-band measurements of the dissipation factor of the dielectric employed in the stripline. A similar estimate from manufacturer's data indicated that the insertion loss can be reduced to 2 dB by employing 50 mil alumina substrates.

One Stage L-Band Amplifier

The 1.5 GHz output from the filter is amplified to a level of 160 mW in a one stage amplifier employing a 2N5715 transistor. Values for the components of the input and output matching networks were experimentally determined. The collector is connected to the dc supply through the center conductor of the eyelet feedthrough capacitor, which also provides an ac ground for the inductor. Input bias is supplied through a quarter wavelength line terminated by a feedthrough capacitor.

Future Plans Uncertain

Future plans called for a continuation of the development effort in the areas of temperature compensation and g-hardening. The crystal oscillator provided adequate frequency stability over the -40 to +60 C temperature range, but additional compensation will be required to maintain the transmitter power output level constant. Also, it should be possible to stabilize the amplifier stages by replacing the fixed bias resistors with appropriate temperature compensating resistors. The filter has adequate bandwidth and needs no compensation.

With the exception of the low loss capacitors and the 2N5715 transistor, all circuit components were qualified for an artillery environment. Prototype printed circuit boards were not qualified, since it was intended to fabricate the final version on ceramic substrates. It was also planned that the entire unit would be tested at shock levels up to 40,000 g following current shock tests on the capacitors and the 2N5715 transistor.

Individual boards subsequently were fabricated and tested up to 40,000 g, and a complete unit was assembled. However, attempts to initiate pilot production at commercial facilities failed. Because the requirements to fabricate these units in mass at HDL do not exist, further in-house work has been postponed.

JOHN RODD is a Project Leader in the Advanced Engineering Section at the Benet Weapons Laboratory of Watervliet Arsenal. He has worked at this facility of the U.S. Army Armament Research and Development Command since the early 1960's following several years' work in General Electric research labs. At Watervliet, Mr. Rodd has developed expertise in machinability, contributing to the industrial base manufacturing effort related to cannon in the specific areas of trepanning, abrasive machining, and ceramic tooling. He has achieved recognition for his expertise in these fields by the American Ordnance Association and the Tooling and Manufacturing Engineering Society. A graduate of government industrial training centers, he has published articles in his field in the majority of the major industrial magazines.

Photograph

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THOMAS M. WRIGHT is the Coordinator of ARRADCOM's ManTech activities at Watervliet Arsenal, where he serves as Chairman of the Technical Working Group for MM&T Planning. He also is a member of the CAD/CAM Subcommittee of the DoD/Industry Manufacturing Technology Advisory Group and serves on DARCOM's CAM Steering Group. Prior to joining the staff at Watervliet six years ago, Mr. Wright operated his own construction business. He has a B.S. in Research Methods from New York University at Albany, where he will receive his M.S. in Management in May, 1983.

Photograph

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Study Shows Designers Not Aware

Selective Surface Finish Cuts Costs

Deliberate, thoughtful analysis of real machining and finishing needs in the production of gun components can save on costs and time, according to a manufacturing technology study recently completed in-house by the U.S. Army Armament Materiel Readiness Command at its Watervliet Arsenal facility. Over design and over specification of surface finish requirements by only a small increment can dramatically increase the total cost of a manufactured component.

A source of manufacturing difficulty often arises during original product design because many designers are not familiar with general overall machining cost factors. For example, specifying a 16 finish instead of a 63 finish increases the component finishing cost by as much as 300 percent. The economics involved in general manufacturing are the result of part specifications; these specifications usually are based on "best engineering judgment" rather than on any cost analysis or relationship of required surface finish to final product cost.

The products manufactured by Watervliet Arsenal range from massive cannon tubes that weigh in excess of 12,000 pounds to smaller items which weigh less than one pound. Some of the items, although considered to be minor components, are extremely complex and therefore difficult to produce. This situation is further complicated by dimensional tolerance and surface finish requirements. Therefore, tolerance and surface finish specifications for both major and minor components are a source of manufacturing difficulty.

As an example, a final product tolerance of ± 0.002 will cause in-process dimensions to be controlled much more closely during the manufacturing cycle to insure that the final requirements are met. Locating or holding fixtures, tooling, gages, and the general step by step manufacturing process must also be controlled and continuously monitored to meet final tolerance and surface finish specifications. This can cause an item to become extremely difficult to produce and therefore more costly.

NOTE: This manufacturing technology project that was conducted by Watervliet Arsenal was funded by the U.S. Army Armament Materiel Readiness Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The Watervliet Point of Contact for more information is Mr. Thomas M. Wright, (518) 166-4231.

Slide Chart Attempted

Because surface finish and part tolerances are the primary factors in dictating final product manufacturing techniques and overall costs, a product survey was undertaken to determine the most advantageous areas to study. Results indicated that the most benefit would result from a combined study of major items such as gun tubes, breech blocks, and breech rings. Engineering drawings, manufacturing routings, and machining techniques were then reviewed to establish areas of principal concentration.

Once the product survey to isolate those areas which have the widest payback ratio was completed, statistical test data was compiled for computer analysis. A slide chart or ready reference chart which depicts machining characteristics then could be produced from the data.

A Solution to the Problem

The review of the statistical test data, however, indicated a new approach. Currently, a reference pamphlet is used to discuss tolerances in general. But it would be much more beneficial to have reference charts that depict the ratio of machining costs versus specified surface finish. This guide would be extremely valuable to design engineers, planners, and shop personnel.

Figure 1 shows the variety of finishes that can be achieved by various manufacturing techniques. For example, to obtain a 4 finish, many separate tools may be involved such as lathes, milling machines, grinders, super finishers, and other highly specialized pieces of capital equipment. The closer the tolerance, the slower the operation. The skilled craftsman must use extreme caution in approaching the final tolerance of ±.001", whereas sawing to a tolerance of ±.125" can be accomplished quite simply and usually without difficulty.

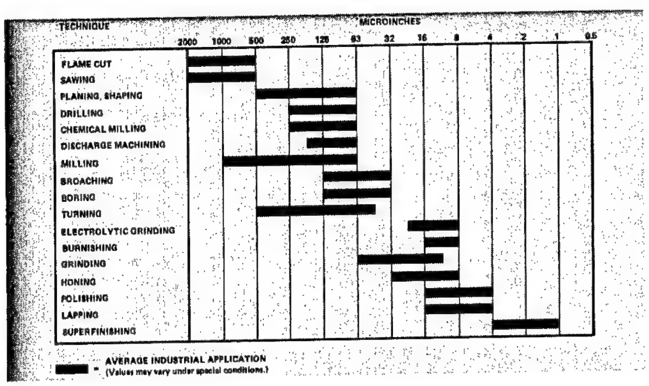

Figure 1

Figure 2 was developed as a result of several tool life tests. This chart was constructed to show the vast increases in machining cost for various surface finishes specified. And, as discussed before, product surface finishes in many instances are arbitrarily dictated. There are situations that demand surface finishes be machined to the 32 finish requirement; however, many of these 32 finish requirements actually are machined somewhere between a 16 and 32 finish. By referring to Figure 2, it readily can be established that to produce a surface finish beyond what is specified will result in an enormous increase in product cost. Therefore, if a finish specification serves no practical purpose, the tolerance should be relaxed until it falls in a category of being economically justifiable.

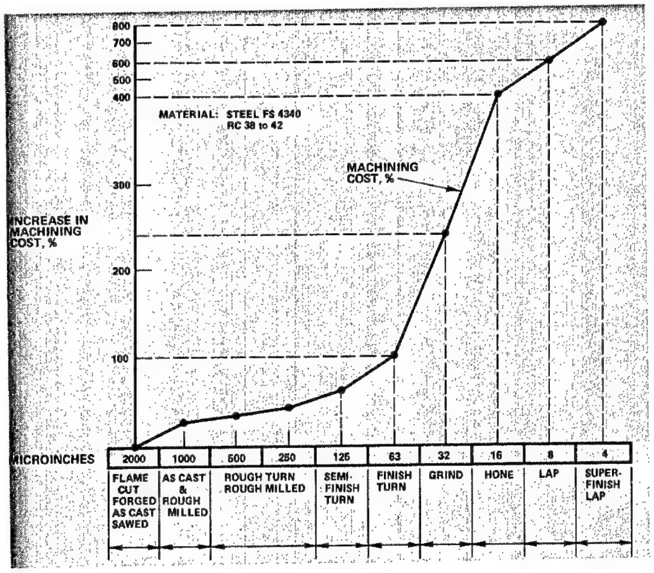

Figure 2

Testing Upholds Need for Charts' Standards

A series of surveys were conducted on the gun tube, breech block, and breech ring of the 105mm M68 gun to see if design specifications were really practical and needed as established.

The survey of the breech block showed that most component tolerances and surface finishes were fully justified and required no modification or clarification.

After a careful review and analysis of all statistical test data, it was determined that the 32 finish requirement for the gun tube could not be maintained by alternate methods of machining—i.e, turning tools alone. In all tests, tool wear could not be controlled and resulted in either an out of tolerance condition for the area machined or an unacceptable surface finish. The present method of grinding was the only acceptable method of producing the specified requirement. On the other hand, many nonfunctioning surfaces such as the bore evacuator zone, the taper zone, and the muzzle end area require only minimal surface quality. Specifying close tolerances and a high degree of surface finish for these areas would result in unnecessary machining time.

Information Useful

It was concluded that surface finish and tolerances do not appear to present any serious burden to the manufacturing process of the breech ring. However, locating dimensions are being held to a much closer tolerance because they are necessary to establish future fixture positioning.

The survey of the component parts of the 105mm M68 gun only tends to confirm that, if surface tolerance and finishing requirements are to be kept most cost efficient and practical, then there is a real need for the information contained in the two charts presented here.

JOHN HONEYCUTT is a Project Engineer for the U.S. Army Missile Command. His areas of experience at MICOM include three years of mechanical engineering work, four years of aerospace engineering in materials and structures, and fifteen years of work in materials engineering. A member of the Alabama Society for Professional Engineers, Mr. Honeycutt holds patents on a Stress Corrosion Measurement Apparatus and an Igniter Wire Insulator Assembly. He received his B.S. in Mechanical Engineering from Mississippi State University in 1960.

Photograph

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Thermomechanics Improve Product

Internal Shear Forging for Missiles

Internal shear forging experiments conducted by IIT Research Institute for the U.S. Army Missile Command have successfully established procedures for producing missile primary structures as monolithic construction with integral ribs. Using shear forging tooling in conjunction with an engine lathe, this MM&T program developed guidelines for large volume production of these structures and showed the cost savings resulting from implementation of the internal shear forging processes.

The major conclusions from this program are that

- Internal shear forging can be implemented to produce missile primary structures to near net shape.
- The cost savings accompanying implementation of this process are substantial.
- Although the strengthening effect of thermomechanical treatment (TMT) seems to be minimal for 2014 aluminum on the basis of tensile data, further testing for fatigue, fracture, and stress corrosion resistance is necessary before the effects of (TMT) can be confirmed.
- Dimensional stability and residual stresses resulting from TMT must be fully characterized.

Before this cost effective, near net shape technology is implemented, however, it is recommended that the thermomechanical aspects of the process be carefully reviewed and evaluated in terms of the following:

- Tradeoff between higher property levels (if existent) and increased processing cost due to multiplicity of steps
- Influence of process variables on the reproductivity of end properties and product appearance
- Magnitude, polarity, and distribution of residual stresses resulting from TMT and their effect on the dimensions and mechanical properties of shear forged subshells.

NOTE: This manufacturing technology project that was conducted by IIT Research Institute was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Mr. John Honeycutt, (205) 876-1074.

Cost Reductions Prime Goal

Missile primary structures currently are fabricated from 2014 aluminum alloy sheet and plate stock by welding together the cylindrical outer skin of the structure and a series of internal stiffening rings. Cost reductions were sought for large production quantities by implementing internal shear forging to produce these structures in monolithic construction. An additional benefit is the possibility of enhancing structural performance by incorporating thermomechanical treatments (TMT) into the internal shear forging process for these structures.

Internal shear forging consists of deforming a cylindrical ring between a rotating external die and an internal roller, resulting in a thin walled tube with integral internal ribs. It is fairly well established as a production process for axisymmetric components and is known by a variety of names including internal tube spinning and internal roll extrusion.

The objective of this program was to establish the internal shear forging process for missile primary structures featuring thermomechanical treatment. For aluminum alloys, TMT typically involves introducing cold work into the precipitation hardening cycle, which results in many cases in improved tensile properties, fatigue strength, fracture toughness, and stress corrosion resistance.

The work performed on this program included tooling design and fabrication, an exploratory study of basic parameters, internal shear forging experiments, processing of deliverable parts with thermomechanical treatment, tensile property determination, and an economic analysis involving considerations of production requirements and costs for internal shear forging.

Work Leads to Important Conclusions

The principal aim of the rolling experiments task was to study the deformation processing characteristics of aluminum alloy 2014, to establish the starting condition of the alloy, and to predict its response to deformation during internal shear forging.

In shear forging, the material is subjected to a reduction in thickness in an incremental fashion similar to the rolling process. Furthermore, because the current method of manufacture for these missile structures utilizes rolled stock, it was decided to study the rolling characteristics of this alloy and to establish, if possible, the desired processing parameters for internal shear forging. Both material related variables and processing variables were considered. The material related variables included

- Alloy temper
- Size and thickness of the workpiece
- Starting, intermediate, and final microstructures
- Presence and distribution of secondary phases.

The process related variables involved selection of parameters like reduction per mass, rolling temperature, lubricant, rolling speed, number of rolling passes, heat treatment between passes, and post-rolling heat treatment. In selecting the range of these variables, due consideration was given to the interrelationships between temperature, reduction, and strain rate, as these variables directly influence the reduction behavior and final properties of the rolled material. Initial roll temperature, temperature and thickness of the starting workpiece, and the heat generated during plastic deformation also influence the final properties and microstructure of the rolled product.

Alloy 2014 is a heat treatable age hardening alloy that contains Al with Cu, Mg, and Si as the main alloying elements. Addition of Si enhances the response to artificial aging (T6 temper), with the final strength being higher than for the naturally aged (T4) condition. This alloy is widely used in structural applications. For deformation processing, it is desirable that the alloy be in a fully annealed (0 temper) condition. The fully annealed temper yields stabilized precipitate phases in a matrix which has high ductility and can undergo a considerable amount of plastic deformation.

Compromise Necessary

For this work, 2014 alloy could not be procured in the fully annealed condition. Therefore, a 1 inch thick rolled plate was procured in the T651 temper (solution treated, stretched 0.5-3%, and then artificially aged). A 150 x 150 x 25 mm (6 x 6 x 1 in.) plate of the 2014 T651 plate was then annealed at 413 C (775 F) for 2 hours to achieve the annealed condition (0 temper) before processing.

Microstructures were examined by optical microscopy as well as scanning electron microscopy (SEM). Energy dispersive X-ray (EDX) analysis was employed for all identification of various constituent phases. All microscopy specimens were etched with Keller's reagent. Tensile strength values quoted here were obtained from the longitudinal (parallel to rolling) direction unless specified otherwise.

The rolling experiments led to the following conclusions:

(1) It is essential that the starting condition of the 2014 alloy for bulk deformation processing be in a completely annealed condition in order to achieve maximum ductility of the matrix with stabilized precipitates. In the present study, this condition was not achieved to the desired extent, perhaps because of the T651 temper of the starting material.

(2) The present experiments indicate that at higher temperatures deformation rates (from changing the rolling speed) do not produce a pronounced change in the appearance of the grain structure. Shear forging of the proposed part may involve localized differences in deformation rates, but the present results indicate that this should not pose any serious problem.

(3) Post-rolling heat treatment experiments demonstrate that the utmost care must be exercised during solution treatment in order to achieve the desired strength and ductility in the final product. Grain boundary melting can be avoided if the solution treatment is preceded by a homogenizing anneal at a lower temperature. Precise temperature control is, however, extremely important.

Tooling Design and Fabrication

A heavy duty engine lathe (LeBlond Model 2516) was converted into an experimental shear forging machine. Some of the important aspects of tooling design for internal shear forging—based on the metalworking requirements imposed on the tooling components—were roller design, die construction, and surface finish (Figure 1).

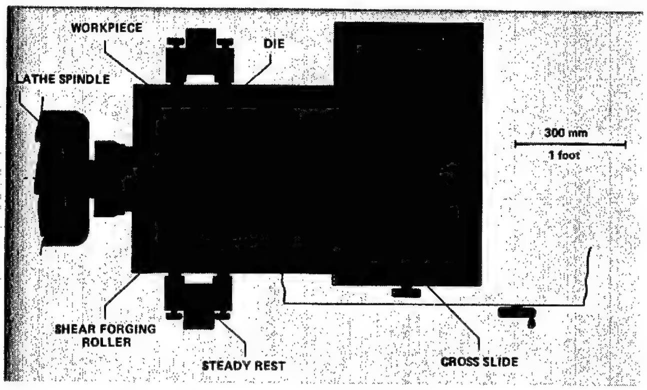

Figure 15

To minimize deflections and enable the lathe to perform capably under the high forces generated during shear forging, the loading and support members of the tooling were "boot strapped" together (Figure 2). The loading path thus generated would go from the roller arm directly to the interconnected support arm, with load transfer to the lathe possible only in the event of gross misalignment.

Application to Subshells

Using the modified tooling, thick walled 2014 O-rings were successfully shear forged into thin walled internally ribbed tubes. Thermomechanical treatments were evaluated by introducing cold work at various stages of the precipitation hardening cycle for the workpiece material. Lubrication during the initial passes—which were made at about 177 C—was accomplished using a graphite spray on the workpiece. Solution treatment was done in a Globar heated electric furnace at 55 C. The final passes following solution treatment and different preaging treatments were made at room temperature (to prevent overaging) using a light oil for lubrication.

Metal Flow

Various types of metal flow were encountered in internal shear forging. A near uniform flow of metal under the roller with no folding of metal ahead of the roller typically occurred after the first two or three passes, with gradual heating and increased plasticity of the workpiece enabling higher percent reductions to be taken. In the initial passes, the metal flow was usually less uniform because of loading limitations and insufficient percent reduction in the wall. An extensive case of nonuniform flow included intense shearing of the surface layers of metal, with formation of dead metal zones, folds, and laminations. In contrast, the rib forging operation that was performed to orthogonalize the rib section produced uniform flow of metal under the roller despite some shaving of the vertical face of the rib due to friction. Numerous structure defects were observed in the early trials which had to be studied and resolved.

In addition to 2014 Al (program alloy), a few tests were conducted with 2024 workpieces fabricated from plate by roll bending and welding. In contrast, all the 2014 Al workpieces were ring rolled to provide a weld free structure. The as formed skin showed decreasing strength with increasing wall reduction. This is not the expected result of softening during mechanical working, since the preform was fully annealed to begin with and the processing was conducted below the recrystallization temperature. However, it may be an evidence of the Bauschinger effect, since the tensile tests reversed the polarity of the stress field present during forming.

The strength levels after heat treatment to the T6 condition showed no significant effect of deformation behavior, the yield and tensile strengths being in accordance with handbook data for these materials.

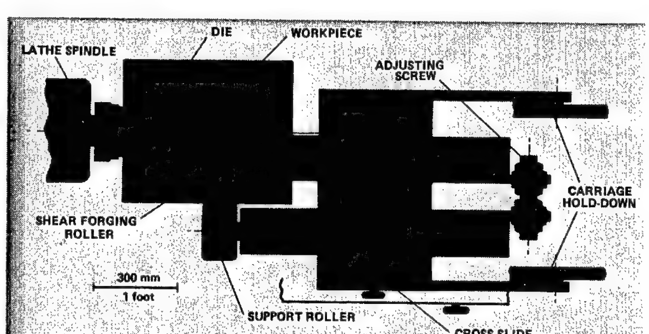

Figure 2

Thermomechanical Treatment

Thermomechanical treatment (TMT) is a means of improving the properties of certain alloys by introducing plastic deformation into the heat treatment cycle. The microstructural changes accompanying the process are different from those in conventional processing. Depending on the alloy and the nature of the TMT, this can result in improved tensile strength and elongation, better fatigue, creep, and wear resistance, and higher levels of fracture toughness and stress corrosion resistance.

Six different TMT cycles were evaluated; they differed from one another primarily in the stage of the precipitation hardening sequence in which cold work was introduced. In addition, the time and temperature of preaging (after solution treatment, before cold work) was varied wherever possible to investigate the precipitation kinetics to a limited extent. In all cases, the starting material was a ring rolled and fully annealed ring of 2014 aluminum. In general, cold work following solution treatment is seen to fragment the grains, with the most dramatic fragmentation occurring when cold work is imposed on a fully aged T6 structure.

Response Marginal

On the basis of the tensile properties measured, a double aging TMT cycle was selected for production of the deliverable subshells. Two other cycles were selected for preparation of samples for further testing by MICOM.

In general, cold work appears to hasten the precipitation hardening kinetics of 2014 aluminum. The final aging temperature thus has to be lower than for conventional artificial aging to the T6 condition to avoid overaging.

The tensile test data indicates that the response of 2014 aluminum to thermomechanical treatment is only marginal insofar as tensile properties are concerned. Although higher strengths have been attained here than in conventional T6 heat treatment, it has been at the expense of ductility (tensile elongation). The effect on fatigue strength, fracture toughness, and stress corrosion cracking would be evaluated by MICOM, if warranted, external to this program.

Deliverable Subshells

Three deliverable subshells were processed. This involved shear forging (170 C), rib forging (170 C), solutionizing and quenching, artificial preaging at 170 C for 1 hr, shear forging (cold) by 10 percent, final artificial aging at 150 C for 10 hr, and trimming to size. In addition, the skins of an additional subshell section were processed by T6 and T9 treatments and delivered to MICOM for metallurgical and mechanical testing.

It was observed that internal shear forging with TMT—with the final passes performed cold on a preaged structure—resulted in considerable residual stresses. These stresses were either nonexistent or not apparent when shear forging annealed parts at warm temperatures.

The target component was intended to be internally shear forged, leaving the central region as a single thick rib. Grooving the thick rib in a lathe setup then would generate two separate thin ribs. However, in producing the deliverable subshells, it was not possible to machine the rib to the desired specifications: the shear forging die was designed as a split (two piece) construction held together by tangential bolts to facilitate part removal after forming. Under load, the two piece assembly was progressively distorted (and the bolts stretched), resulting in an oval die and, hence, subshells with approximately 1.6 mm (1/16 in.) ovality.

It was decided not to machine the ribs so as to avoid the risk of breaking through the skin and rendering the subshells unusable.

Later experiments showed that a split die is not necessary and that by reverse feeding the roller, the part can be forcibly extracted from the die. A strong, rigid, single piece die thus could be used to eliminate ovality and rib machining problems.

Production Requirements and Costs

The capital equipment for internal shear forging consists primarily of one or more heat treating furnaces and one or more heavy duty engine lathes or (preferably) spinning lathes. The quantity of each of these items would be determined by the cycle time and the rate of production desired. Tooling for internal shear forging would be modified as necessary to suit the particular spinning machine used. Additional items include a lubricant spray system, an oxyacetylene heating system (optional), and material handling equipment.

An annual requirement of 2000 parts calls for one spinning lathe ($200,000) and three heat treating furnaces ($300,000) for solutionizing, preaging, and final aging. The total investment in implementing the new technology in place of the current process is estimated to be $1,000,000. The annual return on this investment is expected to be $6.86 per dollar invested for a payback period of 1.7 months.

The shear forging die, rollers, support members, and other items of tooling are expected to cost $100,000, including rework and replacement parts for one year's production. Amortization over 2000 parts will result in a tooling add-on cost of $50 per part.

The labor requirement for internal shear forging of 2014 aluminum subshells with thermomechanical treatment has been estimated at 12 standard hours per part, whereas the current process of fabricating the subshell as a welded structure was estimated to consume 130 standard hours per part. The production costs derived from these figures show that shear forged subshells would cost about one-eighth that of comparable fabricated structure

Attractive Process Holds Promise

Ferrite Phase Shifters From Arc Plasma

RICHARD W. BABBITT is a Senior Electronics Engineer with the U.S. Army Electronics Technology and Devices Laboratory, Fort Monmouth, N.J. A graduate of Lehigh University, he received a B.S. in Engineering Physics in 1958. He is engaged in research and development of millimeter wave materials and control devices.

Work at the Electronics Technology and Devices Laboratory of the U.S. Army Electronics Command has demonstrated that a low loss lithium ferrite phase shifter can be economically fabricated with the arc plasma spray (APS) process. Also, it can be expected that lower microwave losses can be achieved by arc plasma spraying than by the more conventional processes.

An attractive feature of the arc plasma process is that it can readily adjust to changes of phase shifter design and frequency range with a minimum of expense. This feature proves the arc plasma process to be economical for the fabrication of a much smaller number of phase shifters than other processes.

Original Work With Nickel Zinc

The primary objective was to establish an economical ferrite powder suitable for the arc plasma fabrication of C-band and S-band nonreciprocal ferrite phase shifters. The original effort to arc plasma spray ferrites was with nickel zinc ferrite powders. These powders were prepared by flame spray, fluid bed, and spray dry processes. APS techniques were developed for spraying thick deposits greater than 20 mil at deposit rates in excess of 50 mil/min/sq in. Also, a microwave magnesium maganese ferrite was deposited with good hysteresis properties and low dielectric loss tangent. These results indicated the feasibility of arc plasma spraying a microwave quality ferrite around a dielectric, thus forming the basic ferrite phase shifter configuration.

Arc Plasma Deposition Economical

A ferrite phase shifter is a long ferrite toroid with a dielectric inserted in the center (Figure 1). The length and cross sectional dimensions will vary with different applications and frequencies of operation; however, the fabrication technique remains relatively the same. The current technique used in fabricating this phase shifter requires a ferrite toroid with close dimensional tolerances, machining, and the insertion of a dielectric into the toroid. Some designs require the drawing of cement into the ferrite-dielectric interface to insure that no air voids exist. The assembly of the ferrite and dielectric adds significantly to the cost of the phase shifter and can affect device per-

NOTE: This manufacturing technology project that was conducted by the Army's Electronics Technology and Devices Laboratory was funded by the U.S. Army Electronics Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ECOM Point of Contact for more information is Mr. Richard W. Babbitt, (201) 544-2284.

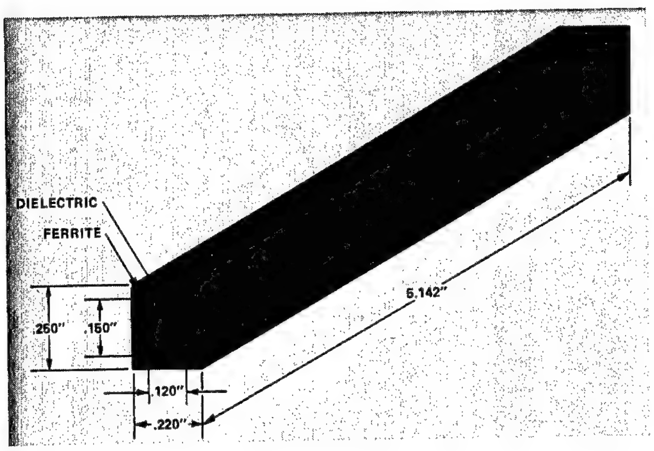

Figure 1

formance. The arc plasma deposition of a ferrite around a dielectric presents a more economical process for fabricating phase shifters, since an intimate ferrite/dielectric bond can be achieved with the arc plasma process.

Arc Plasma Gun Used to Melt and Project Powder

An arc plasma gun is used to melt a ferrite powder and project it onto a target (Figure 2). The heat produced by the arc plasma is dependent upon the arc current and arc gas. However, the heat to which the powder is subjected depends on the point of the plasma stream into which the powder is fed.

The powder can be fed internally into the arc gun, or externally at some place in front of the arc gun (Figure 3). The internal feed is the more efficient for melting the powder; however, volatile elements can be lost, oxides are more readily reduced, and "loading" may occur. Loading occurs when the powder melts before leaving the gun (anode), where it resolidifies and builds up, interfering with the plasma stream and resulting in pieces of the ferrite breaking off and depositing on the target. An external feed eliminates the possibility of loading, but more heat is required to melt the powder, causing greater difficulty in feeding all the powder particles into a uniform heat zone of the plasma.

A compromise of these two powder feeds is to use a cover which is not as susceptible to loading as the internal feed, yet restricts the powder to a narrow temperature zone. Regardless of the technique, it is necessary that the powder be fed with velocity capable of penetrating the plasma stream, thereby producing a sufficient melt. The velocity of the powder is controlled by the powder carrier gas flow rate and the size of the powder port. After the powder is in the plasma stream, the degree of melt it will experience is dependent upon the heat available and the time in the plasma (dwell time). Dwell time is controlled by the arc gas flow rate, the temperature to which it is heated, and the size of the nozzle (anode). Smaller nozzle ports are considered high velocity nozzles. The three variables which determine the plasma velocity are

- The arc gas flow rate
- The temperature to which the arc gas is heated
- The nozzle size.

After the feed powder has been melted, the arc plasma deposits it on a target. A good deposit results when the powder reaches the target in a molten state. The conditions which contribute to the powder striking the target in a molten state are

- The distance from the gun to the target (spray distance)
- The speed at which the powder travels
- The ambient temperature from the gun to the target.

The more complete the melt and the greater the impact of the target, the denser the deposit and the stronger the bond. The bond which can be achieved with the arc plasma process is the feature which makes this process attractive for the fabrication of phase shifters. However, for the arc plasma process to be economical, it must deposit ferrite powders at fast rates around a dielectric and with the required magnetic properties.

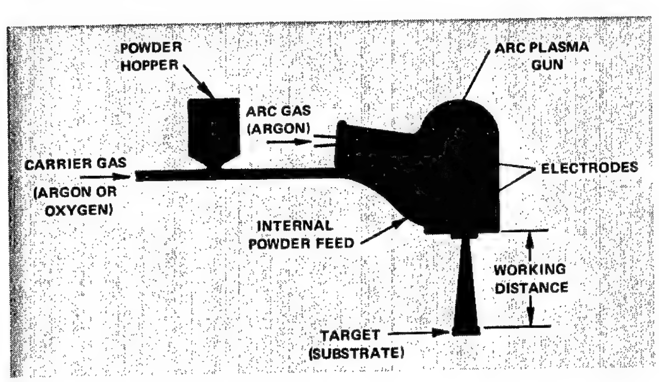

Figure 2

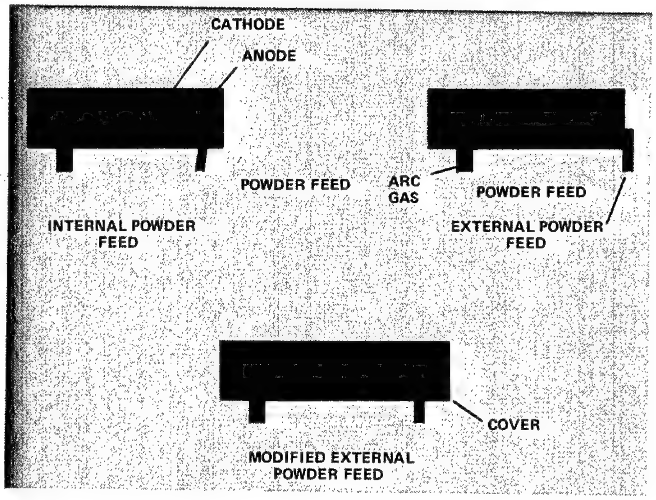

Figure 3

Best APS Parameters Found

A powder for arc plasma spraying bulk ferrite bodies must be free flowing to obtain a uniform and high deposition rate. Two other powder characteristics which influence the spray process are the particle size and size distribution. It has been established that particle size influences the deposit density. High density deposits were achieved with lower spray parameters (arc current) for small particle sizes. A powder with a large size distribution has a greater tendency to load, since the arc plasma parameters are normally set to melt the mean particle size. This causes the smaller particles to melt before clearing the arc gun, while the larger particles are not sufficiently melted to produce a dense deposit.

Compositions of lithium ferrite and yttrium iron garnet were selected for the arc plasma fabrication of C- and S-band phase shifters. Lithium ferrite was the primary composition since it is less expensive than garnets and, with proper substitutions, it can be tailored for several microwave frequency bands. Ampex's Ferrite Materials Division was chosen as the supplier of ferrite powders used in this program.

Deposit Efficiency (Dep. Eff.) is the percentage of powder sprayed which is deposited around the dielectric. The Dep. Eff. is very important to the economics of the arc plasma fabrication of phase shifters. Not only does it directly affect the deposition rate, it also affects the amount of powder required to spray a phase shifter. A high Dep. Eff. requires that the ferrite powder be sufficiently melted to adhere to the dielectric and that the powder hit the dielectric. Thus, not only is the aim of the plasma gun important, but also the cross section of the dielectric in relation to the spray span. Dielectric inserts of most phase shifters are relatively small targets for the arc plasma spray and much of the powder misses the dielectric. The Dep. Eff. for the S-band phase shifter is approximately 40 percent compared with 25 percent for the smaller C-band dielectric which is sprayed with a cover to limit the spray span. Improved cover designs should produce a narrower spray span, increasing Dep. Eff. and deposition rate.

The deposition rate for phase shifter fabrication is defined as the thickness of ferrite deposited in one minute around a one linear inch length of dielectric (mil/min/in). The deposition rate is dependent on the Dep. Eff. and the amount of powder fed to the plasma gun. Even with the relatively low Dep. Eff., deposit rates as high as 80 mil/min/in. can be achieved. Normally, 12 grams of powder per minute is fed through the arc plasma gun to produce a deposite rate of 50 mil/min/in.

Arc Plasma Spray Parameters

The determination of how the arc plasma parameters affect the magnetic properties was done with stress free samples. Stress free samples are obtained by separating the deposited ferrite from the dielectric before annealing. In this manner the anneal relieves any stresses resulting from a coefficient of expansion mismatch between ferrite and dielectric. Two arc plasma guns were evaluated—one with an internal powder feed and one with an external powder feed. It was possible to achieve low microwave losses and good hysteresis properties with either gun. However, different spray conditions were required for each gun in order to achieve satisfactory material properties. The significant difference is that the internal feed gun had to be operated with much higher plasma velocities, no helium, and at a greater spray distance. The internal feed generally produced samples with higher densities but was susceptible to loading and had a more limited range of acceptable spray parameters compared with the external feed gun. The external feed gun, modified with a cover, was selected for the bulk of this effort.

Dielectrics for APS Phase Shifters

A program to develop dielectrics for inserts for the APS fabricated lithium and yttrium iron garnet phase shifters was initiated by the Ceramic Group of the U.S. Army Electronics Technology and Devices Laboratory. The dielectric requirements were

- Low microwave loss
- High dielectric constant (K)
- A similar thermal coefficient of linear expansion as the ferrite to be deposited

Fabrication Technique

Using established spray parameters with an appropriate anneal cycle, it is possible to arc plasma spray lithium ferrite with suitable microwave properties around a dielectric which has a close matching coefficient of expansion. The arc plasma fabrication process is done by spraying ferrite on a rotating dielectric. This spraying process is done in an oven (Figure 4), which is preheated to decrease thermal shock and enhance ferrite deposition. While the dielectric is rotating, it is pulled past the stationary arc plasma gun once until the desired length is coated. The rate of pull and the ferrite deposition rate determine the deposit thickness. The ferrite is oversprayed from 20 to 50 mil, and then the outer dimensions are machined to tolerance.

Utilizing this fabrication technique, no expensive tooling is required for design changes of the phase shifter or for spraying phase shifters for different frequency bands. When two differently designed C-band phase shifters were sprayed in sequence, the only requirement was that a different size dielectric be used and the rate of pull adjusted for the change in ferrite wall thickness.

The Future

Based on spray times, it can be expected that for higher frequency devices the arc plasma process will be even more attractive when compared with any current or experimental technology. It is also expected that, as more advanced arc plasma spray techniques are developed, improved and lower cost phase shifters will be realized. One

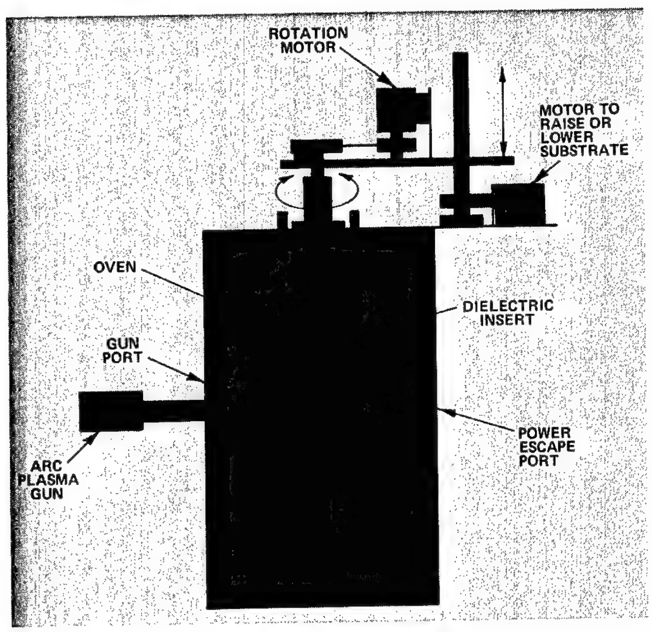

Figure 4

such improvement will occur when spraying is done with the drive wires in place. This will not only reduce cost by eliminating two dielectric halves, but it is also expected to reduce the need for mode suppressors, since the ferrite phase shifter will be one solid composite from dielectric to waveguide, without any air voids.

It is important to remember the significant fact that this arc plasma spraying effort was done with powder designed for conventional sintering processes. It can be expected that improved devices will be achieved with ferrite powders specifically developed for the APS. It has already been established that fully reacted powders are desirable for the APS process. In addition, it has recently been found that a powder with a narrow size distribution improves the reproducibility of the APS process. Neither of these two characteristics—i.e., fully reacted powders with narrow size range—are generally desirable for conventional sintering processes. Finally, the newer arc plasma guns with higher power and higher velocity should also contribute to improved materials and devices from the arc plasma process.

Technique Modifications Required

Plasma Spray for Millimeter Wave Shifters

NOTE: Mr. Richard W. Babbitt, author of the article on ferrite phase shifters on page 31, also is the author of this article. His biographical sketch can be seen on page 31.

Arc plasma spraying (APS) techniques for fabricating phasors for millimeter frequencies from 35 to 95 GHz have been developed successfully in a manufacturing technology project completed by the Army's Electronics Technology & Devices Laboratory for the U.S. Army Electronics Command. These new techniques will reduce the cost of producing these devices up to 75%, according to conservative cost projections.

Arc plasma spray techniques previously were developed for fabricating low microwave frequency nonreciprocal ferrite phase shifters (3 to 6 GHz). The purpose of this phase of the work was to demonstrate the feasibility of the APS process for fabricating low cost, high performance, nonreciprocal millimeter wave ferrite phase shifters. The ferrite phasor (Figure 1) for operating at 35 GHz has a dielectric thickness which was varied between 9 and 18 mils and a ferrite wall thickness which was varied between 15 and 22 mils. This design produces maximum differential phase shift and minimum insertion loss per unit length for a ferrite composition.

As previously noted, when conventional fabrication techniques are used to produce millimeter ferrite phasors, they are difficult to reproduce, are expensive, and generally provide inadequate performance characteristics. Conventional techniques require material processing, tooling, and machining whereby numerous time consuming steps are required to meet stringent dimensional tolerances in order to minimize air voids at the ferrite-dielectric interface. The small size and tight tolerance of the ferrite toroid and dielectric insert are responsible for the high cost of millimeter phasors, and unavoidable air gaps at the ferrite-dielectric interface produce inadequate device performance.

The APS process has been successfully used to fabricate lower frequency 3 to 6 GHz phasors. During the low frequency effort, it was recognized that the greatest economic impact of the APS process would be realized for higher frequency phasors. The APS deposition of a ferrite around a dielectric is a simpler and more economical pro-

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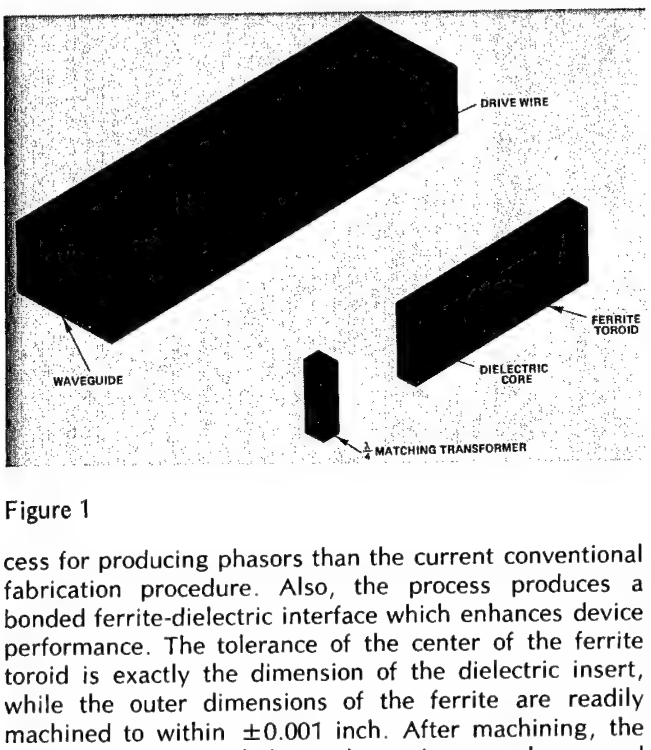

Figure 1

cess for producing phasors than the current conventional fabrication procedure. Also, the process produces a bonded ferrite-dielectric interface which enhances device performance. The tolerance of the center of the ferrite toroid is exactly the dimension of the dielectric insert, while the outer dimensions of the ferrite are readily machined to within ±0.001 inch. After machining, the APS phasor is annealed to reduce microwave losses and coercive force prior to device testing.

Fabrication

A lithium ferrite powder was selected for spraying millimeter phasors, since a lithium ferrite composition can be tailored to have a high saturation magnetization to 5000 G with a square hysteresis loop and can be annealed at relatively low temperatures. The arc plasma spray equipment and procedure used to spray millimeter phasors was the same as that used for the lower frequency C and S band phasors. However, the thin dielectric of millimeter phasors necessitated a modification of the arc plasma spray parameters and a new technique for placing a drive wire.

Because thin dielectrics are very susceptible to warping during spray procedure, the APS parameters were modified. They included spray distance, arc current, and plasma velocity (arc gas); spray distance was increased, while arc current and arc gas were decreased. The low arc gas decreases the plasma velocity, which increases the dwell time, thus compensating for the lower arc current. The spray distance was the most critical parameter, with variations of 0.25 inch having a significant bearing on warpage. However, it was desirable to have the spray distance as short as possible, since this parameter also has a significant effect on the ferrite deposition rate.

The large dielectrics used for C and S band phasors were sprayed as two slotted halves joined together, forming a center hole for a drive wire. The dielectric used for millimeter phasors is too thin for this technique to be practical. The technique selected was to form a hole for the drive wire during the fabrication of the phasor. An inexpensive and simple procedure was developed which required bonding a thin piece of boron nitride to the dielectric. The boron nitride maintained its size and shape during spraying but was completely burnt out during the anneal cycle, leaving a hole for inserting a drive wire. Using this technique made it possible to determine hysteresis properties when the hole was large enough for two wires. However, due to the thin ferrite wall (less than 0.022 in.), stresses from a coefficient of expansion mismatch and machining stresses are more critical than experienced for the C and S band phasors.

Device Performance

The first phasors tested were those fabricated from the 1200 G lithium ferrite. The 1200 G composition has a rela-

tively high dielectric constant—17, thus it is not possible to achieve an ideal match to the quarterwave boron nitride transformer, especially with the high K lithium titanate dielectric. This accounts for the relatively narrow bandwidth achieved for these phasors. Bandwidth is also restricted by spurious modes generated when the phasor is heavily dielectrically loaded. The greater phase shift with the higher K dielectric is due to the greater concentration of RF energy in the phasor.

Evaluation of APS phasors fabricated with a 4100 G lithium ferrite was initiated after the evaluation of several of the 1200 G APS phasors had been completed. The phasor from this initial small batch of 4100 G powder had maximum remanent magnetization of 1800 G. A computer program based on an 1800 G remanent magnetization and a dielectric insert with a K of 26 predicted a theoretical differential phase shift of 336 degrees per inch. The APS phasors produced 300 degrees per inch differential phase shift, which is approximately 90 percent of theoretical. (See Figure 2.)

Although the conventional phasor possesses a higher remanent magnetization than that of the APS toroid, the APS phasor produces more than twice the differential phase shift. This is due to the fact that the APS phasor is loaded with a higher K dielectric and lacks air gaps at the ferrite-dielectric interface. It can be projected that, as the 4100 G lithium ferrite powder is modified for the APS process, remanences approaching 3000 G will be realized. A remanence of this magnitude will produce 500 degrees per inch differential phase shift.

Projected Costs Tell the Story

Currently, it takes less than 2 minutes to spray a 1 inch phasor. Based on the APS operating costs, the spraying costs are less than $4 per phasor. Using the $4 per phasor spraying cost and including the dielectric cost, $5 is the cost projection for arc plasma spraying a 35 GHz phasor. The machining cost for the APS 35 GHz phasor is estimated to be less than $10. This cost figure is based on our machining experience and a current $18 cost for machining an APS C band phasor, which requires significantly more machining. Allowing $5 for profit and an 80 percent yield, a 35 GHz APS phasor will cost less than $25. This estimate assumes no significant improvement in the APS technology; and more important, it should be realistic for small quantities—i.e., one hundred or more phasors. This estimated cost—$25 for an arc plasma fabricated 35 GHz phasor—can be compared to a current price in the range of $100 for a conventional ferrite toroid. However, there still are significant costs associated with inserting the dielectric, also a questionable yield.

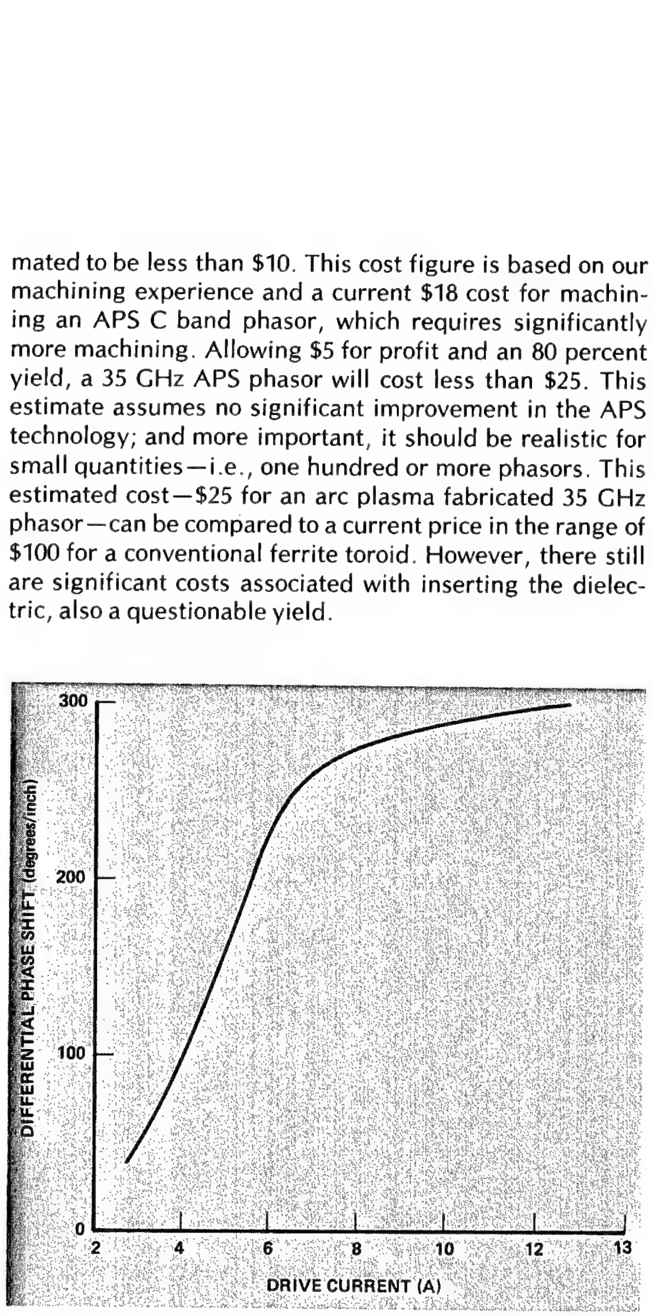

Figure 2

Brief Status Reports

Project 4310. DMSO Recrystallization of HMX/RDX. The current method of recrystallizing HMX/RDX is inefficient and uneconomical. It requires large amounts of raw materials (especially cyclohexanone or acetone), proccess vessels, and manpower. A solvent with much greater soluating power is required. DMSO is such a solvent and can be used for processing large amounts of HMX/RDX. This project is developing a pilot scale process for recrystallizing HMX/RDX using DMSO. Continuous operation of the DMSO pilot line was successfully demonstrated. Design rate was achieved with some equipment problems. Preliminary qualification testing of pilot plant recrystallized material was initiated. Finished explosives made from DMSO recrystallized RDX/HMX were shipped to Lone Star and Louisiana AAP for end item testing. At LSAAP, M112 demonstration charges were loaded with composition C-4. About 53 of the 72 scheduled interim qualification tests were completed. No adverse effects due to DMSO recrystallized explosives was noted. Long term storage tests were conducted; M55 detonators and grenades were fired successfully. For additional information, contact R. Goldstein, ARRADCOM, (201) 328-4122, or D. Yee, MPBMA, (201) 328-2243.

Project 4311. Develop Automated Production Equipment for XM 692. The present production facility to LAP the XM692 mine dispensing system is limited to a manual/manual assist operation with attendant production unit costs and high personnel exposure. This project will provide equipment designs and prototype equipment to automatically load and assemble the XM37 mine, thereby reducing personnel hazards and production costs while providing a more uniform and reliable item. The plug puller passed acceptance testing and is in production at LOAAP. Two machines are in production and two are 90% debugged. For additional information, contact L. Weiner, ARRADCOM, (201) 328-5538, or M. Condit, MPBMA, (201) 328-2712.

Project 4466. Evaluation of TNT, Cyclotol, Octol in Melt/Pour Facility. The melt/pour explosive fill equipment was designed for the Army's preferred fill, Composition B, with little regard for the application of this equipment to the alternate explosive fills. This project will develop melt/pour utilization plans for the processing of TNT, Cyclotol, and Octol. The K-Tron Weighfeeder was selected to feed TNT to the mixer. Cost growth of \$239K was approved to assure a complete evaluation of the TNT solids mixer with live explosives. Installation drawings, preliminary survey of the instrumentation and control system, and fabrication of the S. Howes mixer were completed. The controlled cooling equipment has been installed. For additional information, contact L. Manassy, ARRADCOM, (201) 328-3890, or B. Waldman, MPBMA, (201) 328-4071.

Project 4469. Automatic Insertion of Grenade Layers. The manual insertion of grenade layers into projectiles is a highly manual, costly, and hazardous operation. This project will develop automated equipment to perform the insertion of grenade layers into the M483-155mm Projectile. Final design drawings for the grenade insertion system were completed. Fabrication and assembly work was completed and the machine was successfully demonstrated. For additional information, contact L. Weiner, ARRADCOM, (201) 328-5538, or M. Condit, MPBMA, (201) 328-2712.

Project 4480. High Speed Head Turn Tool Modification for SC Ammunition Production. The SCAMP case submodule has continuously experienced excessively high usage rate of head turn tool modules. This is due more to the tool module going out of adjustment than to breakage of tooling. This project will evaluate two designs to improve the head turn tooling. The first design uses a self opening hollow mill to replace the cutter and roller guide presently used. The second design includes new methods of holding the piece for head turning. For additional information, contact M. Leng, ARRADCOM, (201) 328-5688, or S. Ward, MPBMA, (201) 328-2712.

Project 4484. Improved Hi-Speed Waterproofing Application for SC Ammunition. The primer lacquer and mouth waterproofing applicator systems on the SCAMP primer insert submodule periodically fail to perform as required. The misapplication results in expensive rework. The current primer system will be replaced with a precision pumping system. The mouth waterproofing system will employ a two part probe for increased efficiency. A less labor intensive reservoir filling method will be investigated. For additional information, contact M. Leng, ARRAD—COM, (201) 328-5688, or S. Ward, MPBMA, (201) 328-2712.

Project 4498. Consolidation and Automatic Assembly of Small Mines. Offline operations and multiple handling are required for the predominately manual LAP operations. This project will provide the process procedures for consolidating within the mine housing, also concepts for automation of the assembly operations and a final report. Designs were approved for an automated lens tester and auto-

mated soldering machine. The contractor is proceeding with fabrication of equipment based on these designs. For additional information, contact J. Bracilgliano, ARRADCOM, (201) 328-5569, or M. Condit, MPBMA, (201) 328-2712.

Project 4503. New Process for SAW Tracer Ammunition. There is no U.S. capability for manufacturing the proposed NATO 5.56 Tracer Bullet in the quantities required for the SAW system. The conventional small caliber tracer bullet manufacturing equipment will be modified to produce the Nato Tracer Bullet. For additional information, contact S. Kaszupski, ARRADCOM, (201) 328-4687, or B. Hajduczok, MPBMA, (201) 328-2742.

Project 4335. Alternative Process for Titanium Gyroscope Components—Copperhead. Contemplated production methods are costly and remain essentially unchanged from those used to produce components for the engineering development version. This project will apply and prove out a more cost effective production technique specified for the manufacture of each gyro component. Test specimens were forged and hot isostatic pressed using different titanium compositions. Preforms were designed, compression properties and preform sintering process determined, and sample HIP studies performed. Four of five gyro parts have been successfully fabricated using selected powder metal processes. Tensile tests of both commercially pure Ti and Ti-Ga-4V Ti alloy have been performed to verify properties. For additional information, contact R. Pellen, ARRADCOM, (201) 328-3237, or T. Gutch, MPBMA, (201)328-4084.

Project 4349. Modernization of Press Loading for HEP Projectiles. Labor intensive loading of high explosive projectiles generates wasteful increments and machining of excess explosives. This project will develop prototype automatic increment feed system and automatic adjustment of increments for limited/or no machining of fuzz. The first increment netweigher has been installed and checked out for operation. All equipment and accessories were installed. Prototype and inert tests were completed. The press will have to be sent to another facility for live loading. For additional information, contact R. Daywalt, ARRADCOM, (317) 854-1669, or E. Feddema, MPBMA, (201) 328-4071.

Project 4364. On-Line Bio Sensors to Monitor Mixed Waste Streams. PL92-500 requires that waste discharges be monitored to assure that aquatic life is protected from toxic/hazardous substances. In addition, biological monitoring soon will be required in some national pollution discharge elimination system permits. This project will use a biological monitoring system to evaluate toxic effects. From correlations between chemical constituents in the waste water and biological responses, expensive chemical monitoring might be eliminated. For additional information, contact D. Johnson, ARRADCOM, (301) 671-2586, or K. Wong, MPBMA, (201) 328-4076.

Project 4139. Application of Radar to Ballistic Acceptance Testing of Ammunition. Present radars in use at the proving grounds have limited capability, are adaptations of tactical systems, and lack real time data processing capability. This project will develop a radar based instrumentation system for use at the proving grounds for the improved ballistic acceptance testing of ammunition, reduction of personnel, and provisior of long range project tracking capability and improved data reduction. Antenna pedestal and servo control box have been mounted and checked. A special purchase processor has been tested and the phase frequency scan antenna was installed. The system was shipped to Yuma Proving Grounds and dynamic testing using 4.2-in. mortar rounds was started. Some modifications of programs and algorithms is required. For additional information, contact J. Secko, AR—RADCOM, (201) 328-3140, or L. Casey, MPBMA, (201) 328-4071.

Project 4139. Application of Radar to Ballistic Acceptance Testing of Ammunition—ARBAT. System testing is continuing using 60mm and 81mm mortar rounds. Various target intercept modes were tested and system software was corrected and improved. Intercept and tracking performance is gradually improving. For additional information, contact J. Secko, ARRADCOM, (201) 328-3140, or L. Casey, MPBMA, (201) 328-4071.

Project 4149. Loading of 30mm ADEN/DEFA HEDP Ammunition. The loading of ammunition presently is tailored for costly low volume production and is not readily adaptable to large scale production. Projectile bodies can be made by an impact extrusion process at a significant cost savings. A blank, cup, and draw process can also be used as an alternative. The contract for the project was signed with Honeywell. Design of projected fluted liner and charge loading was finalized. A process for projectile fabrication was tested and adopted. Hot forging of shaped charge liners proved feasible. Parameters for charge pressing were set. Three hundred fluted liners were fabricated by hot forge process with close tolerances. Projectiles were

charged and scheduled for qualification tests. For additional information, contact F. Stulb, ARRADCOM, (201) 328-4851, or C. Monroe, MPBMA, (201) 328-4081.

Project 4303. Acceptance of Continuously Produced Black Powder. There is a lack of a quality assurance system in a continuous process which defines and assures reliable performance of black powder in end item use. This project will improve the accuracy and rapidity of assessment and insure desired quality by identifying and controlling all important source material and process parameters. A flame spread test device was developed, tested, and modified. Indiana AAP started characterization of special black powder samples. Static test fixtures to simulate M28B2 artillery primer, 155mm center core charge, and 8-in. propellant charge were fabricated. Preliminary tests were made and showed the fixtures were working as intended. For additional information, contact S. Blunk, ARRADCOM (201) 328-2856, or R. Collins, MPBMA (201) 328-2822.

Project 4305. Production Techniques for Improved WP 155mm Smoke Munition. Production requirement for 155mm WP XM825 has been established in FY84 and FY85, but no production facility is currently available. This project will perform manufacturing process studies to prove out the feasibility of production filling and closing of the XM825. Equipment design was completed and detail drawings for nozzles and volumetric cylinders were provided. Fabrication of components for the fill machine are complete and are being installed along with the control system. Prove-out of WP filling, closing, and leak testing was successfully completed. Two hundred rounds were filled and closed with the equipment. For additional information, contact F. Stewart, ARRADCOM, (301) 671-2863, or W. Ng, MPBMA, (201) 328-2786.

Project 4062. Auto Manufacture System for Mortar Increment Containers. Design efforts are under way at FMC Corporation for the establishment of slurry vacuum forming and paper molding based manufacturing systems and at Innova, Inc. for the establishment of an automated assembly system. The slurry vacuum forming and paper molding based manufacturing system detail packages have been completed. The assembly system design is approximately 60% complete. For additional information, contact P. Bonnett, ARRADCOM, (201) 328-5839, or C. Imbesi, MPBMA, (201) 328-2792.

Project 4064. Auto LAP Operations for 105mm Tank Cartridges. Present manual techniques used for these items are very labor intensive and lack reproducibility, while being extremely costly. This project will design an assembly system which will be capable of repetitively assembling the 105mm tank cartridges more consistently and at a cost savings. RISI Industries was awarded the contract for the development study and the design program. A practical production line system for the load and assembly of a family of 105mm tank cartridges has been designed and is in various stages of design execution and verification. For additional information, contact K. Lischick, ARRADCOM, (201) 328-4162, or L. Casey, MPBMA, (201) 328-4071.

Project 4124. Fabrication of Control Actuation System Housings. The housings used in tactical weapons control systems are the single high cost item in the system. These housings are expensive because MID volume production capabilities have not been established. This project will provide a computer numerical control (CNC) multimission center capability to produce these housings at an annual rate of 12,000 to 50,000. The project has been awarded to Chandler-Evans. Preliminary tool and fixture specifications for the 5 and 8 inch housings have been completed. The programming and package design aspects are near completion, and tool and fixture purchases have begun. For additional information, contact R. Pellen, ARRADCOM, (201) 328-3237, or T. Gutch, MPBMA, (201) 328-4084.

Project 1335. Manufacturing Technology for New Protective Mask. Fabrication of one piece plastic masks with adequate optical characteristics is difficult. Vision reduction and distortion are critical. This project will develop a manufacturing process to alleviate production problems defined by PEP effort. Manufacturing plan, plant layout, and DIPEC search were completed. Contract was awarded to Mine Safety Appliance for procurement, setup of presses, molds, and controls for pilot plant. Specification and purchase request for a lens molding and assembly clean room were prepared. Process engineering work for coating automation was completed. For additional information, contact F. Martin, ARRADCOM, (201) 328-2970.

Project 1339. Chemical Agent Detector Production Waste Disposal. A chemical agent is needed to provide the dye for use as a liquid agent detector. This project will develop an alternative manufacturing process using a noncarcinogenic intermediate in the synthesis of the B-1 dye. M8 detector paper booklets were incinerated in the chaingrate incinerator at Pine Bluff Arsenal successfully. Stack gases were monitored and indicated no organic CODS were released into the environment. For additional information, contact D. Lee, ARRADCOM, (201) 328-3912.

Project 1403. Improved Process/ Substitution of Nontoxic Dyes—M18 SMK Grenades. Current dye mixes used in yellow and green smoke munitions are known to be toxic and are suspect carcinogens. This project will improve/modify process to eliminate exposure of manufacturing personnel to the toxics and/or use of substitute nontoxic dye mixes. The chemicals, grenade hardware, and fuzes were ordered and received. For additional information, contact M. Smith, ARRADCOM, (301) 671-3223, or S. Nemiroff, MPBMA, (201) 328-2786.

Project 4024. Design Development Building Prototype Auto Assembly Machine for M223 Fuze. High density items produced on hand lines with slow speed auto equipment need higher productivity with minimum capital equipment costs. This project will develop high speed automated assembly equipment to reduce capital equipment costs for large quantity production. The contract was awarded to Innova, Inc. Concept designs were reviewed and detailed designs started. The screw and weight assembly machine and the slide assembly machine designs were completed. For additional information, contact W. Badowski, ARRADCOM, (201) 328-4638, or W. Carrigan, MPBMA, (201) 328-4081.

Project 1312. Paper, Chemical Agent Detector, M8. The pulp used to manufacture M8 paper only retains up to 50 of the required dyes. This results in a significant loss of dyes and a corresponding disposal problem. This project will incorporate dye retaining aids into the pulp as it is being processed, or in with the dyes prior to putting the dyes in the pulp to effect maximum dye retention. A kinetic dispersion mill was installed and 5 gallon quantities of each dye were redispersed and diluted to 30% solids. Tests indicate that all three dyes used in M8 paper are mutagenic. A safety SOP and protective requirements were developed. Modifications to the pilot facility were made to permit work with the dyes. Paper runs to evaluate retention aids and analysis of dye retention in paper have been completed. An increase of 11.5 percent in indicator dye retention was demonstrated. For additional information, contact P. Annunziato, AR—RADCOM, (201) 328-4424.

Project 1327. Improvement/Modernization of Gas Mask Leakage Testing. The M14 testing technique is archaic, tedious, and semiquantitative. It requires undue maintenance and strain on operators to obtain reproducible test data. This project will use state of the art gas detection system (ionization detectors, electron capture, or others) to test masks. M9A1 and M17A1 masks were sent to the Southern Research Institute for use in preparing test head fixtures. Prototype testers were manufactured which demonstrated ability to detect leaks near the 0.5cc/Min. requirment. Several possible alternate aerosols were evaluated and some were found to be suitable. For additional information, contact A. Kohut, ARRAD—COM, (201) 328-3608.

Project 6350. Road Seal Test Machine. This effort has multitasks. These include studies of carburized gear case depth, residual and near surface stresses, and multifrequency eddy current inspection techniques. The MTMIS data base does not maintain data on subtasks. For additional information, contact H. Hatch, AMMRC, (617) 923-3555.

Project 0915. Group Technology Requirements Definition (Electronics). Classification, coding systems, and group technology have been developed and used for batch manufacturing of machined parts. Potential exists for applying these techniques to electronics. Through evaluation and analysis of the perceived needs for a group technology classification and coding system for electronics components, a definition of the essential parameters to which such a system should respond will be developed. For additional information, contact N. Scott, ARRADCOM, (201) 328-6430.

Project 1295. Modular Charcoal Filter Test Equipment. Charcoal filter testing equipment to provide testing capability for various chemical agents does not exist. This project will design a modular testing system for various filter systems. A concept for the facilities requirement was prepared. The CSL safety office prepared a safety site plan and obtained approval from the DOD explosive safety board. For additional information, contact R. Morrison, ARRADCOM, (201) 328-3808.

Project 6390. Program Implementation and Information Transfer. The success of the MMT program is very dependent on whether the results of MMT work are implemented. This in turn is dependent on whether information concerning the MMT technology is made available and used by concerned parties. This project will insure that the MMT results are documented and given wide distribution so as to encourage implementation. For additional information, contact R. Farrow, AMMRC, (617) 923-3521.

Project 4462. Modernization FAD for Multibase Propellants. Forced air drying process and facilities must be modified to reduce the pollution emissions and at the same time recover valuable propellant material. This project will develop recovery equipment to reduce pollution emissions and provide more efficient heating plate coils coupled with lower air velocities. About 10 propellant drying runs were conducted on M30, M30A1, and M31A1 in the modernized FAD bay. About 20% more propellant was capable of being dried than in a conventional bay. Drying tests were successfully conducted with various multibase propellants in the FAD bay. Propellant was dried in greater quantity at lower air flow rates than in a conventional bay. For additional information, contact A. Graff, ARRADCOM, (201) 328-5572, or W. Heidelberger, MPBMA, (201) 328-3651.

Project 3572. NG-Nitrate Ester Removal by Absorption/Recycle. An operating procedure for a new absorption column was modified to include new flow rates and sampling frequencies. Bench scale apparatus and supporting equipment was moved into a new approved facility. Wastewaters containing NG and DNG were passed through an absorption column containing XAD-4 resin. Preliminary hazard analysis of the nitrate ester removal system was complete. Stability tests and DTAS were performed on NG and DNG loaded resins. Four tests of the modified 2-bed downflow absorption/denitration system and evaluation of alternate denitration solutions were performed. Small lab-scale studies to obtain isotherm and denitration data on degon loaded resins was initiated. For additional information, contact W. Buckley, ARRADCOM, (201) 328-3572.

Project 4444. Body for M42/M46 Grenade. The present method of producing the body for the M46 and M42 grenade is costly. This project will determine a more economical method to produce the body for the M42 and M46 grenades. Two scopes have been prepared. The contract was awarded to Dyron Corporation, which has submitted design drawings for a one piece M46 body. For additional information, contact V. Grasso, ARRADCOM, (201) 328-4638, or P. Ng, MPBMA, (201) 328-3730.

Project 4449. Process Improveent for Composition C-4. The existing facilities which are common to the manufacture of composition B and the other RDX composition would limit the availability of these items below their MOB requirements. This project will establish new processes and methods for the manufacture of these items to minimize the impact of common operations on capacity. For additional information, contact G. Eng, ARRADCOM, (201) 328-3717, or T. Sachar, MPBMA, (201) 328-2497.

Project 4460. Continuous Mixer-Illuminant Composition Analysis and Control System. An on-line analysis and proper control of illuminant compositions prior to consolidation to insure process integrity in illuminating candle production is not available. This project will develop a prototype automatic process control for illuminant composition consisting of sodium nitrate magnesium and an organic binder. Vendor system evaluation and equipment selection are complete. X-ray fluorescence analysis was selected after testing for the facility at Longhorn AAP. It will measure Mg, NaNO3, and binder to 3% in 14 minutes vs 2 hr, using the existing method. For additional information, contact R. Wolfe, ARRADCOM, (201) 328-2188, or S. Nemiroff, MPBMA, (201) 328-2786.

Project 4267. Continuous Process for Granular Composition B. The batch-wise cooling process of RDX/TNT/WAX slurry allows only a limited control of granulation. This project will develop and use a continuous process to produce granular composition B. A meeting between the coordinating organizations was held to determine initial design criteria and the steps necessary to establish a prilling tower to produce 500 lb/hr granular composition B. Drop/impact tests were performed on cast composition B charges impacting a steel plate. There were 31 drops with no incidents. Lone Star AAP was selected as site for granular composition B pilot plant facility. For additional information, contact R. Manno, ARRADCOM, (201) 328-4205, or T. Sachar, MPBMA, (201) 328-2497.

Project 4214. Pollution Engineering for 1983-85 Requirements. The Federal regulations for environmental control are changing and becoming more stringent for 1983 and 1985. This project will adopt new technology, especially in the areas of recycling and reuse of waste material, to provide conformance with 1983 and 1985 regulations. This project is an orderly transition of pollution abatement methods for propellants and explosives and is directed to meeting future standards. Refer to the four individual tasks for any changes and/or additional information regarding the project. For additional information, contact J. Swotinsky, ARRADCOM, (201) 328-4284, or K. Wong, MPBMA, (201) 328-4076.

Project 3901. Manufacture of Fluidic Amplifiers by Cold Forming. Present methods of manufacturing fluidic amplifiers are costly, as they require 100 percent inspection because of unsatisfactory repeatability in dimensions and finishes. This project will adapt the cold forming manufacturing process to the production of aluminum fluidic amplifiers. Drawings for three laminates to be fine blanked have been generated, reviewed, and accepted. Fabrication of the tooling is in progress. For additional information, contact J. Joyce, ARRCOM, (309) 794-3080.

Project 3907. MNOS Countermemory Circuit for Fuzes. There has been no production capability for the low cost, long lead time countermemory circuits for XM587. This project evaluated low cost encapsulating methods to replace expensive ceramic package for the counter circuit and ensured a production base by continued purchases of the circuits. For additional information, contact N. Doctor, HDL, (202) 394-3114, or D. Booker, MPB—MA, (201) 328-4081.

Project 4145. Control Drying in Automated SB and all Propellants. Offline analysis for moisture and volatiles makes it difficult to control a continuous drying operation since the time required for analysis is long compared to the residence time for the propellant in a continuous dryer. This project will use product temperature and/or on-line analyzers and flow meters as a basis for improved control of a continuous drying operation and reduction of the amount of offline analysis required. A survey of process instrumentation (gas chromatograph, flow recorders, etc.) has been initiated. For additional information, contact C. McIntosh, ARR—COM, (301) 328-4123, or T. Gropler, MPBMA, (201) 328-2841.

Project 4189. High Fragmentation Steel Production Process. The current production process for manufacturing HF1 projectiles is extremely expensive. Proprietary production processes developed by private industry are not available. This project will examine new and improved production processes for reduction of starting weight, machining techniques, annealing forgings, one-hit hot nosing, heat treating, and fracture toughness. About 234 forgings are made. Multiple size reduction is being attempted and preliminary machining has begun. The incorporation of a mathematical model in forging design is under way. For additional information, contact W. Sharpe, ARRAD—COM (201) 328-4123, or G. O'Brien, MPBMA, (201) 328-3730.

Project 4200. TNT Crystallizer for Large Caliber Munitions. TNT melt loading requires an optimum ratio of molten and solid TNT in the explosive mix at the time of pour. The ratio is obtained by the addition of flake TNT to a quantity of molten TNT based on operator judgment. This project will develop a device which utilizes molten TNT to generate a slurry consistency through partially controlled steady state crystallization. By close control of TNT flow rate and thermal parameters, a continuous fine grained slurry mix of proper ratio will result. For additional information, contact F. Daly, ARRADCOM, (201) 328-5839, or B. Waldman, MPBMA, (201) 328-4071.

Project 4150. New Manufacturing Processes for SAWS Ammunition. The manufacture of penetrators into ball bullets is very costly. This project will investigate skewed axis roll forming of penetrators as well as hybrid slug manufacturing and feeding methods. Cold heading also will be evaluated. Kinefac Corporation delivered 5000 roll formed penetrators for analysis. Waterbury-Ferrel delivered 1500 cold head penetrators. This project was completed with the delivery of tools for cold heading and skewed axis roll forming of the XM777 penetrators. For additional information, contact S. Kaszupski, ARRCOM, (201) 328-4687, or B. Hajduczok, MPBMA, (201) 328-2742.

Project 4281. Synthetic Natural Gas for Process Operations. A comprehensive survey of fuel requirements for process operations at RAAP was completed. An engineering evaluation of coal gasification processes and related technology is continuing. A final technical report is in the process. For additional information, contact D. Casey, ARRADCOM, (201) 328-3998, or H. Ricci, MPBMA, (201) 328-4076.

Project 4285. TNT Equivalency Testing for Safety Engineering. Present criteria for blast resistant structures is in terms of surface burst of hemispherical TNT. In structural design, to protect from the output of other energetics, the designers must have data pertinent to the material in question. By testing to generate peak pressure, possible impulse data from blast measurements of high energy materials is generated. These results are compared with the blast output of hemispherical TNT to determine the TNT equivalency of the material. For additional information, contact J. Marsicovete, ARRADCOM, (201) 328-3906, or L. Casey, MPBMA, (201) 328-4071.

Project 4288. Explosive Safe Separation and Sensitivity Criteria. Data is required to upgrade processes and material for the maximum safety of personnel and equipment against explosion propagation. Tests will be designed and conducted for explosive depth on conveyors. Vertical and horizontal position distances for the

105mm M456 Heat-T projectile was established. Test conditions for the detonator inspection machine test were established. For additional information, contact J. Marsicovete, ARRADCOM, (201) 328-3906, or L. Casey, MPBMA, (201) 328-4071.

Project 4291. Blast Effects in the Munitions Plant Environment. Most of the design effort is in the area of lace reinforced structures for closing in areas to an explosion. We must attempt to utilize common construction material. This project will study characteristics of the blast environment and determine the response of the various structural materials and elements subjected to these loadings. Report completed on blast capacity of strengthened steel buildings. This will provide data for design of economical blast resistant steel buildings. For additional information, contact J. Marsicovete, ARRADCOM, (201) 328-3906, or L. Casey, MPBMA, (201) 328-4071.

Project 4231. In-Plant Reuse of Pollution Abated Waters. More stringent standards for military unique pollutants are reflected by the 1985 goal of zero discharge. The expense of treating pollution is high and plans are to continue this reuse of treated water in other processes. This project concentrates effort in recycling of treated waste water with the ultimate goal of complying with the zero discharge guideline. The 900 (81mm mortar line), 1000 (105mm line) and 1100 (CBU line) areas at Kansas AAP were identified as practical, economical areas for recycle/reuse of pollution abated waters. Y-line (metal parts line) at Louisiana AAP was similarly identified. The analysis was completed and the water qualification criteria for eventual recycle/reuse is being generated. For additional information, contact S. Buckley, ARR—COM, (201) 328-3572, or K. Wong, MPBMA, (201) 328-4076.

Project 4298. Evaluation of Dimethylnitrosamine Disposal on HAAP B-Line. Effluent from ammonia recovery column contains significant amounts of dimethylnitrosamine (DMN). DMN is one of the EPA consent decree compounds for which water quality criteria must be provided. EPA insists on levels below 0.3 PPB. Coordination meeting held between ARRADCOM, USAMBRDL, USATHAMA, USAEHA, PBMA, and HAAP. Work effort was identified and work designated to each organization. For additional information, contact J. Buckley, ARRCOM, (201) 328-3572, or H. Ricci, MPBMA, (201) 328-4076.

Project 4309. Process Development for 120mm Tank Ammunition. Mass production in the United States of West German 120mm tank ammunition poses problems in four functional areas; metal parts, propellant, fuze, and LAP. This is a multiyear effort in four functional areas; a separate task addresses each unique problem. This MMT supports facility project in FY 83-84 and is essential to fielding the 120mm gun system on the XM1 tank in FY85. The manufacture of NC was successfully completed in the first attempt. Boiling times were related to viscosity. The loading process parameters and methods developed by the R&D loading studies were analyzed. For additional information, contact J. Mola, ARR—COM, (201) 328-2210, or LTC W. Shelton, MBPMA, (201) 328-3049.

Project 4266. Manufacturing, Inspection and Test Equipment for Magnetic Power Supply. Piezoelectric power supplies used in heat ammo have undesirable voltage generation impressed on the electrical circuits of the round (due to shock vibrations resulting during flight) which may cause prematures. This project will move the power supply from the nose of the round to inside the PIBD fuze housing and change it to a magnetic pulse generating type power supply which is unaffected by the problem of shock vibrations. The detail design of the assembly station was completed and a functional layout of the line established. For additional information, contact E. Bisson, ARRADCOM, (201) 328-5584, or W. Carrigan, MPBMA, (201) 328-4081.

Project 3532. Molten Salt Lithium-Chloride Battery. The present lead/acid and nickel/iron batteries often need recharging in order to complete an eight hour shift. This project is to establish methods for producing in quantity lithium chloride molten salt batteries. The cell and battery were redesigned to meet special needs of Army forklift program. The battery will now be constructed with felt rather than fabric BN separators in the cells. For additional information, contact E. Dowgiallo, MERADCOM, (703) 664-5309.

Project 4322. MMT Design/Characteristics of Electronic Control System for Production Facility. Uncertainty of the effect of long term storage during plant layaway on electronic control systems and the associated impact on production base lead time. This project will analyze data concerning degradation of electronic systems during periods of dormancy and develop criteria for layaway planning and future system design. A reliability prediction model for Joliet AAP and Volunteer AAP was developed and documented in a technical report. A plan has been prepared for 11 Army facilities to prepare electronic process control systems for layaway and reactivation. For additional information, contact L. Doremus, ARRCOM, (201) 328-3084, or G. DeVoe, MPBMA, (201) 328-4071.

Project 3960. Prototype Producing Equipment—Printed Circuit Boards. R&D designs experience in-process problems when transferred to large sheet multiarray commercial production. Problems include flow solderability, line width, and in-process handling. This project will fabricate prototype producing equipment for printed circuit boards using production techniques normally used in the industrial sector to assure compatibility of the TDP with mass producability. Harry Diamond Laboratory used its prototype producing equipment to verify design packages for SEAGNAT and JAMMER. They found problems while building the circuit boards and informed the design group. New plotter, exposer, developer, etcher, laminator, and component inserter were used. For additional information, contact R. Baker, HDL, (202) 394-2820, or D. Booker, MPB—MA, (201) 328-4081.

Project 3961. Improved 3-D Vibration Accept Test F/M732 M724. Current methods are costly and time consuming, rarely expose the test item to true service environments, and require three tests to account for all test axes. This project will show use of computerized 3-D vibration/shock testing as an acceptance tool to solve technical and economic test deficiencies. Test time is reduced. The system engineering definition task is under way. Specifications for the shaker system were developed and procurement of two LING systems initiated. A finite element model of the test platform was developed and a draft TDP was prepared. For additional information, contact A. Frydman, ARRCOM, (202) 394-2804, or D. Booker, MPB—MA, (201) 328-4081.

Project 4312. Injection Molding for Production Explosive Loading. Melt loading of small explosive items normally requires large surpluses of moltent explosive to obtain good filling char. Surplus riser material can be twice the amount loaded into end items. Very small items cannot be effectively melt loaded at all. This project will develop an injection molding system for filling small items with explosive charges to finished dimensions and reduce surplus explosive requirements to very low levels. Injection loading equipment for BLU 63 bomblets was designed and fabricated. About 112 BLU 63 bomblets were loaded with Composition B. The results were acceptable. For additional information contact P. Scherchock, ARRADCOM, (201) 328-4252, or M. Condit, MPBMA, (201) 328-2712.

Project 6350. Chemical Analysis of Silicon Nitride. The silicon nitride samples were examined for yttrium content by emission spectroscopy. Samples contained 14-16 percent yttrium. Silicon content was checked by atomic absorption. A method was established for fabricating "glassy disks" from a mixture of silicon nitride powder densified with either yttrium or cerium, thorium nitrate added as an internal standard, and lithium tetraborate as the fusing agent. For additional information, contact B. Strauss, AMMRC, (617) 923-3555.

Project 1353. Smoke Mix Process (Glatt). The installation of a bulk transfer system was completed. Continued evaluation of four binders on each of 4 M-19 mix colors. Continued test program to confirm formulas and to determine operational parameters in the full scale Glatt granulator. Initiated a 12 week environmental storage and long term ambient storage test. Initiated preparation of final technical report. For additional information, contact D. Garcia, ARRCOM, (501) 541-3573, or S. Nemiroff, MPBMA, (201) 328-2786.

Project 4033. Caustic Recovery From Sodium Nitrate Sludge. Holston AAP currently is losing $80 for each ton of sodium nitrate by-product sold. Sodium nitrate is extremely difficult to dispose of because of competition from other fertilizers on the market. This project will convert sodium nitrate into sodium hydroxide for reuse in spent acid recovery operations at Holston. A substantial cost benefit results by reducing the amount of new sodium hydroxide solution to be purchased. Sludge sample from Holston was analyzed and characterized. A survey found no off the shelf incinerator available. Furnace liner materials are being reviewed to establish design criteria for pilot plant. Lab studies revealed technical problems in processing sodium oxide. Three alternative processes were proposed and an economic analysis was done on each. A contract to obtain an independent analysis of the alternatives was awarded to Battelle's Columbus Laboratories. For additional information, contact G. Eng, ARRADCOM, (201) 328-3717, or A. Schafer, MPBMA, (201) 328-2243.

Project 4281. Waste Heat Recovery. Petroleum may not be available in the future to meet production requirements. This project will develop an energy saving technology to apply to AAP manufacturing functions to reduce the quantity of energy used at all levels of production. AMAF Industries was awarded a contract to perform the waste heat recovery study at Scranton AAP. A waste heat recovery evaluation was completed and a final report was prepared. It describes the technical and economical feasibility for recovering waste heat with a boiler system. Steam would be produced to meet facility steam requirements. For additional information, contact G. Scullin, ARRADCOM, (201) 328-3742, or H. Ricci, MPBMA, (201) 328-4076.

Project 4084. Opacity/Mass Emission Correlation. Forging operations for large caliber ammunition produce smoke that is regulated for both opacity and mass of the emissions. An inexpensive opacity monitor may be used to also measure the mass of the emissions from a smoke stack if properly correlated. Extensive testing at Sunflower AAP established a correlation between mass emissions and opacity. A final report has been prepared providing test procedures and results. For additional information, contact J. Clancy, ARRCOM, (201) 328-3404, or K. Wong, MPBMA, (201) 328-4076.

Project 4137. Automated Loading of Center Core Igniters. The loading of the long slender cloth bag is an area which requires high labor costs and subjects a large number of personnel to hazardous operations. This project will develop a loading station to weigh and load both the center core bag and the base pad. A preliminary scope of work was drafted. For additional information, contact N. Baron, ARR—COM, (201) 328-3269, or J. Bomengen, MPBMA, (201) 328-2763.

Project 1500. Evaluation of Industrial Capability F/Load Commercial Explosives—High Use Munitions. During mobilization there can be a short fall in availability of military explosives. Industry has many safe explosive formulations. Their applicability to military usage is unknown. Industrial capability for filling these military needs is unknown. This project will conduct a program to identify the quantities and types of commercially available explosives that could be used to supplement the Army's production capabilities during emergency production periods. The performance of munitions produced this way will be evaluated. For additional information, contact G. Cowan, ARRCOM, (309) 794-6513, or R. Lerman, MPBMA, (201) 328-2151.

Project 6682. Simulation of Ammunition Production Lines. Methods are needed for designing production lines operating in a real environment that are subject to the uncertainties associated with machine breakdowns and scheduled maintenance. This project will use a computer program to develop simulations of the operation of model line modules for production base modernization and expansion. The GENMOD program and binomial distribution method were used to simulate the metal parts production line at MSAAP for 155mm M483. The results of a buffer analysis became the criteria for evaluation of proposals for material handling equipment. For additional information, contact M. Grum, ARRADCOM, (201) 328-4389, or Y. Wong, MPBMA, (201) 328-4084.

Project 6716. Mathematical Model of Forming Operations for Artillery Design. Trial and error methods and the absence of proven automated design techniques for tooling cause unexpected failures in forming operations and delays in startup of ammunition production lines. This project will develop analytical models and automated tool design methods of critical metal forming operations. Tool designs thus generated will be tested in a production setting to verify the computer models. Proven models are applicable to current and future ITE. Mathematical modeling of the piercing, cabbaging, and blocking operation and the computer coding of these models are completed. For additional information, contact D. Booker, MPBMA, (201) 328-4081.

Project 1903. Die Cast Tailcone and One Piece Skin for BLU-96/B. Current roll forming equipment is limited to six foot lengths; the BLU-96/B skin is ten feet long and grooved. Limited experience exists in building a die for the BLU-96/B tailcone, which is 26 inches in diameter and weighs in excess of 70 pounds. This project will develop a machine that will roll form BLU-96/B skin. Will manufacture articulate die for 2000 ton die cast press and qualify prototype for IPF. Doehler-Jarvis has completed the patterns. R. D. Schultz Co. is finishing the die. Doehler-Jarvis is installing a third 3000 ton die casting machine. Kurt Manufacturing completed the components for the two roll skin rolling machine and seam welding equipment. For additional information, contact A. Gonsiska, MPBMA, (201) 328-4081.

Project 4037. Process Improvement for Plastic Bond Explosives. Present methods of producing PBX compositions are job shop oriented and uneconomical for large scale production projected in the future. This project developed new techniques of coating, drying, and packaging PBX compositions. The first attempt evaluated equipment selected for composition. Laboratory tests indicated that COMP C-4 could be dried with a belt filter with hot air applied to the top surface. It wasn't determined cost effective. For additional information, contact G. Eng, ARRADCOM, (201) 328-3717, or T. Sachar, MPBMA, (201) 328-2497.

Project 4281. Energy Recovery From Wood Waste. The feasibility study of using wood waste as an alternative energy source is complete except for the final report. The study concluded that wood waste is a viable alternative to fossil fuels at NSTL/MSAAP. ARRADCOM made a presentation to the PBMA management staff detailing the study methods and conclusions and offered some possible alternatives to apply this new technology at MSAAP. For additional information, contact D. Casey, ARRADCOM, (201) 328-3998, or H. Ricci, MPBMA, (201) 328-4076.

Project 4226. On-Line Monitors for Water Pollutants. Identification and monitoring of individual military unique effluent pollutants is required by the Water Pollutant Control Act. This project will demonstrate prototype continuous monitors developed under an R&D program by field tests on AAP wastewater effluent discharge streams. An electrochemical analyzer operated successfully under laboratory conditions. The Raman analyzer was reassembled, aligned, and operated successfully with a dilute solution of acetone in water. The hazards analysis of the instrument is nearing solution. For additional information, contact W. Buckley, ARRCOM, (201) 328-3572, or K. Wong, MPBMA, (201) 328-4076.

Project 4417. Use of Red Phosphorus in Smoke Pot Applications. Smoke produced from HC has led to some injuries and is suspected of being a carcinogen. R&D work is being done to develop a red phosphorus mix to replace HC. However, no large scale red phosphorus preparation facilities currently exist. This project will develop the technology and establish a prototype facility which will on a large scale prepare for loading the red phosphorus formulation which is developed in R&D. Completed lab scale studies of feasibility and safety of using airmix mixer. Scale up testing initiated. Muller mixer procured. For additional information, contact M. Smith, ARRCOM, (301) 671-3223, or W. Ng, MPBMA, (201) 328-2786.

Project 4454. Auto Inspection Device for Explosive Charge in Shell-CAM. The present method of inspecting loaded projectiles utilizes a standard radiographic film method. Labor and material (film) are costly. Determination of critical defect is subject to human judgment, fatigue, and error. This project will develop prototype system using a minicomputer to analyze X-ray images to automatically accept or reject groups of the filled projectiles. It will also develop a prototype filmless real-time automated inspection system. The engineer model general performance requirements have been defined. The contractor for this model has verified the requirements. The producibility difficulties associated with the engineer model detector rollimator have been resolved. For additional information, contact G. Drucker, ARRCOM, (201) 328-5496, or L. Casey, MPBMA, (201) 328-4071.

Project 4474. Dehumidified Air for Drying Single Base Propellant. Humid air requires more energy to dry single base propellant. This project will experiment with dehumidified air to save energy. Bench scale equipment for drying single base propellant with dehumidifed air has been set up and is currently being debugged. Nine drying tests on M6MP propellant for 155mm projectiles were conducted using the bench scale drying equipment. Temperature and relative humidity were varied. Test results are being evaluated and a final technical report is being written. For additional information, contact P. Mullaney, ARRCOM, (201) 328-3258, or H. Ricci, MPBMA, (201) 328-4076.

Project 4059. Optimization—Nitroguanadine in M30 Propellant. Nitroguanidine produced on the new line at Sunflower AAP is expected to have a different particle size distribution than that of the previous supplier. This may create processing problems in the new continuous automated multibase line process. This project is to qualify the nitroguanidine produced at Sunflower AAP on the CAMBL process at Radford AAP and determine if there will be any serious processing problems. Two NQ particle size monitors—one for the crystallizer slurry and one for the final product—were modified and installed. Preliminary standardization was accomplished. An on-line slurry particle size monitor was operated in conjunction with a nitroguanidine crystallizer. Output data are being correlated with data from the air permeability method required by the product specification. For additional information, contact A. Litty, ARRCOM, (201) 328-3837, or T. Caggiano, MPBMA, (201) 328-2179.

Project 4225. Red Water Pollution Abatement System. Red water produced in volume for the purification of TNT is a pollutant for which a satisfactory disposal method does not exist. The feasibility of the Sunoco Sulfite Recovery Process for the disposal of red water has been demonstrated. This project optimizes operating parameters of critical components to support an MCA project for Radford AAP. Purification tests of crude TNT were performed with contaminated sellite. A screw conveyor was successfully tested at the Bonnot Company for extruding repulper mix and slugs of dry ash. Hydrocyclone and solid bowl centrifuge tests were performed on several ash slurry compositions. A sulfite recovery process flow plan and mass/energy balances were completed and provided by the contractor. For additional information, contact W. Buckley, (201) 328-3572, or K. Wong, MPBMA, (201) 328-4076.

Project 1355. Manufacturing Plant Toxic Effluent/Emission Pretreatment. The pollutant discharge permit program requires the use of best available technology for the treatment of designated toxic wastes by 1984. Pine Bluff Arsenal Waste Treatment Facility does not employ the best available technique for these pollutants. This project will identify

manufacturing plant problem effluents/emissions and hazardous wastes and develop treatment criteria. It will also evaluate the need for added equipment and operation criteria. For additional information, contact W. Fortner, ARRCOM, (501) 541-3578, or K. Wong, MPBMA, (201) 328-4076.

Project 4061. Nitroguanidine Process Optimization. A nitroguanidine facility has been under construction at SAAP which utilizes processes not previously used commercially; it contains many recirculation and support loops, the operation of which are strongly interdependent. This project conducted process improvement procedures using nitroguanidine support equipment and installed and applied evolutionary operation to the nitroguanidine facility. A review of the process parameters was completed for all parts of the plant. Maximum and minimum operating conditions were determined. Operations of the NSE during proveout were closely followed. An interim test plan was prepared. For additional information, contact C. Lewis, ARRCOM, (201) 328-3637, or G. Kazin, MPBMA, (201) 328-2243.

Project 1354. Sludge Volume Reduction and Disposal Process Study. MCA pollution abatement facilities under construction at Pine Bluff Arsenal discharge into a settling lagoon having a five year capacity but no cleanout or sludge disposal equipment. To extend lagoon life span, sludge volume must be minimized. This project will provide a process for lagoon sludge cleanout and dewatering for landfill disposal. Volume will be reduced by preclarification and equalization to minimize chemical treatment requirements. Evaluated other treatment chemicals to reduce sludge volume. The design for preclarification/equalization was implemented into MCA-83 project for pollution abatement modification. Pilot dewatering runs yielded sludge cake dry enough for landfill disposal. The project is near completion. For additional information, contact K. Mazander, ARRCOM, (501) 541-3578, or K. Wong, MPBMA, (201) 328-4076.

Project 4210. Dry Cutting of Energetic Materials. Benite strands are cut to required lengths using a milling machine with two circular saws. This is unduly costly because of excessive handling and additional drying and inspection. This project will initiate high pressure water in form of a fine jet stream to cut benite strands. This will reduce the number of operations, eliminate bundling and tying/untying operations, and redrying will be minimized. Work on a safety site plan and review has been initiated. Hazard classification of 1.1 was established and approximately 300 lb of inert propellant simulant was prepared. Concept drawings of material handling equipment were prepared. For additional information, contact S. Lerner, ARRADCOM, (201) 328-3637, or R. Mazinski, MPBMA, (201) 328-2941.

Project 4344. Establishment of Waste Disposal Techniques for M678 Binary Project. Large quantities of solid wastes are generated during manufacturing—there is no acceptable disposal method. Drum storage is not feasible and landfill may require special preparation. This project will develop procedures for decreasing the amount of solid waste generated. Recover wastes in the form of liquid HCL which can be used in the central LWT facility and recycle still bottoms; this will reduce solid wastes by 80 percent. A review and analysis of prior DF production waste work was completed. Initiated effort on evaluation of alternative processes for waste treatment. Prepared and submitted report for review of industrial efforts of DF. For additional information, contact J. Norton, ARRADCOM, (301) 671-4286, or A. Dybacki, MPBMA, (201) 328-4076.

Project 4341. Improved Nitrocellulose Purification Process. Existing nitrocellulose purification facilities were built in the early 1940's and are in deteriorated condition. The process used dates back to WW1 and consumes large quantities of energy and water. This project will select and develop a nitrocellulose purification process to be used in the modernization program which is more energy and water efficient. The method selected is based on the Swiss conicell process as a result of the FY77 effort. Assembly of the unit is being deferred until the concrete pad is poured. For additional information, contact B. Baumann, ARRADCOM, (201) 328-4224, or D. Fair, MPBMA, (201) 328-2841.

Project 4508. Process Improvements for Pressable RDX Compositions. HSAAP is hindered with process bottlenecks in manufacturing Comp B. Processing uses job shop techniques and is labor intensive. Overall production facilities are severely constrained and operate under safety waivers due to outdated technology used. Primary bottlenecks are in the coating and drying areas. This project investigates various ways to eliminate these bottlenecks, evaluate them, and generate sufficient pilot scale data to allow design of the improved process. The final report on the Wolverine Jet Zone Dryer was issued. Composition A-7 dusting problems were eliminated by implementing the modifications recommended in the report. Remaining funds are to be used for installing and debugging the Wyssmont Turbo Dryer system. For additional information, contact G. Eng, ARRADCOM, (201) 328-3717, or P. Juergens, MPBMA, (201) 328-2243.

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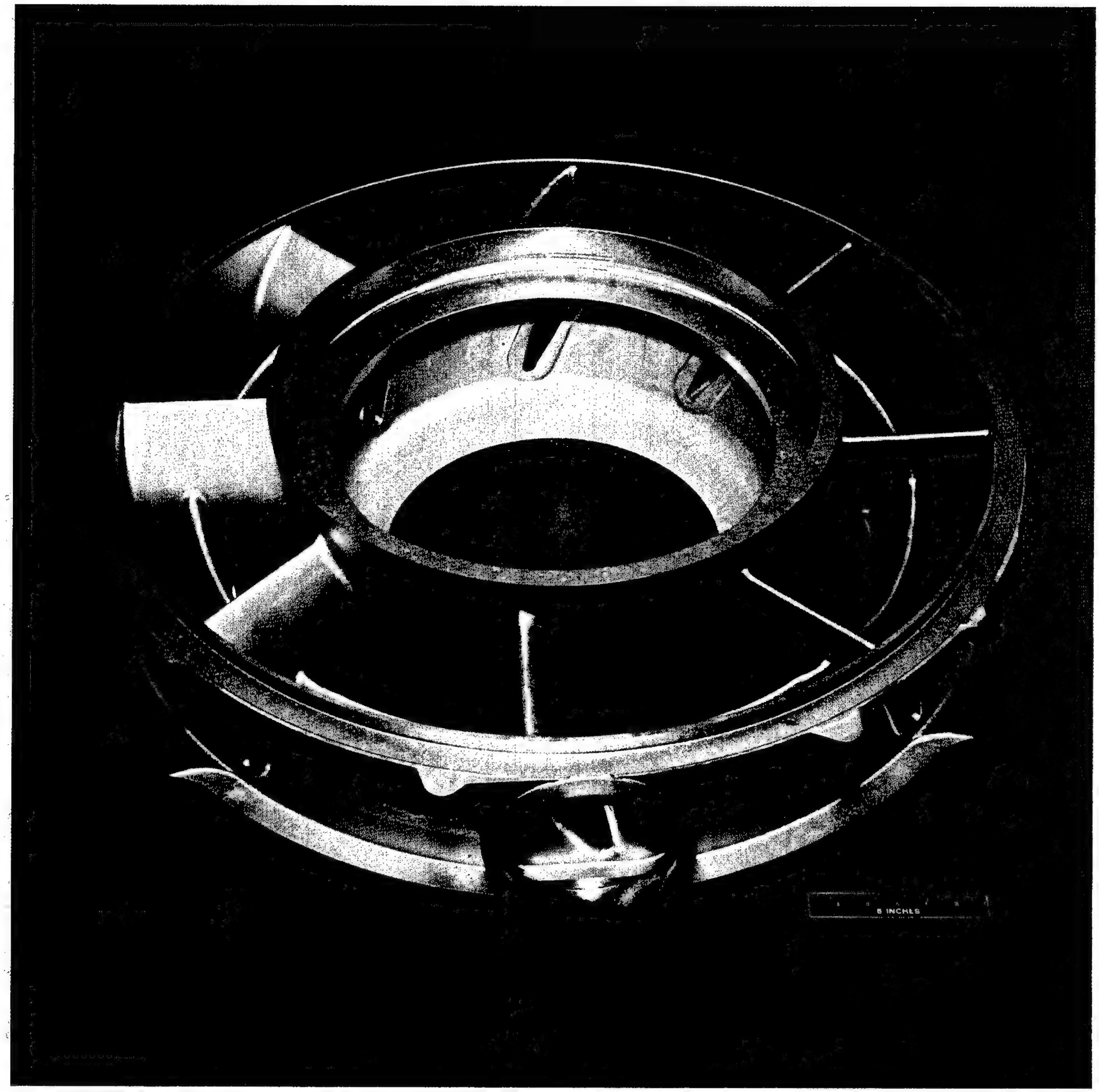
Bridging for the Future

Volume 7/Number 4/1982



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Contents

1 **Comments by the Editor**

3 **Army Aviation Manufacturing Technology Conference III**

4 **Using Composite Materials in Bridging Systems**

9 **Central Lubricant Cooling System**

12 **Brief Status Reports**

22 **Auto Soldering Machine Use On Rise**

24 **Encapsulation of Electronic Assembly**

26 **Chemical Agent Kit Costs Reduced**

31 **Mortar Bodies, Projectile Preforms Squeeze Cast**

36 **New Radiographic Inspection System**

41 **Index by Topic**

Inside Back Cover—Upcoming Events

ABOUT THE COVER:

Production of large, complex titanium alloy castings now is within the current state of the art, as shown by this one piece cast titanium intermediate compressor case for the F100 turbofan built by Pratt and Whitney Aircraft. The raw material buy/fly ratio has been reduced by a factor of 2.25 and savings of 20% in fabrication costs have been realized. Also, 250 lb of unrecoverable machining scrap is saved. For more information, contact Mr. Michael D. Ross, Pratt and Whitney Aircraft Group, 305-844-3254.

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Comments by the Editor


RAYMOND L. FARROW

My associates at the U.S. Army Materials and Mechanics Research Center and I were pleased recently to witness the appointment of one of our former coworkers, Mike Kornitzky, as Chief of Manufacturing Technology at Sikorsky Aircraft. Mike acquired an extensive mantech background during his years at AMMRC, working in the Organic Materials Laboratory here before joining our staff in the Planning Directorate. He served many years as Cochairman of the Nonmetals Subcommittee of the Manufacturing Technology Advisory Group and has been a very active participant in the Army's mantech programs administered by AMMRC. His addition to the Sikorsky staff will provide that organization with a manager of solid technical background possessing an unusually comprehensive perspective of not only the Army's mantech programs, but the other services and industry, too. We at AMMRC are proud to have had him on our staff during the past years and wish him all the best in his new endeavors.

This issue of the U.S. Army ManTech Journal contains several unusual features. One of the most important is the brief report on page 3 of the Army Aviation Manufacturing Technology Conference III sponsored by the U.S. Army Aviation Research and Development Command. AVRADCOM has enjoyed significant productivity improvements from the projects that the previous mantech conferences have produced. The ManTech I Conference included 30 projects funded between FY 78-81 for a total of $9 million; sixty projects were included in the FY 79-83 plan. ManTech II so far has produced 6 projects totalling $2.5 million. Twenty projects have been included in the FY 83-87 plan covered by ManTech III, which is set for Williamsburg, Virginia in March of 1983.

The article reporting on the use of composites in bridging systems by the U.S. Army Mobility Equipment Research and Development Command should provide some interesting response from our readers in the private sector, also those in the Department of Transportation who are faced with a major national construction project in the renovation of the nation's bridges.

A remarkable opportunity is described in the article on a central lubricant cooling system which offers very rapid return on investment following installation of such a system at Army machining centers. Benet Weapons Laboratory personnel are to be commended for their accomplishment.

As has become a regular occurrence in this Journal, this issue features ten pages of brief status reports on ongoing projects. We also have included a topical index through the letter N which will be continued in our next issue. These entries cover the past six issues of the Journal.

Both the U.S. Air Force and the U.S. Navy will utilize a new wave soldering machine developed by the U.S. Army Missile Command, one which has provided highly superior performance over previous designs. This Army funded technological improvement will be shared by the other services on production of several of their hardware items, provid-

ing greater efficiencies, improved product, and considerable cost savings for all military production. We hope the commercial sector, too, will enjoy the benefits of this remarkable new technology.

Lower costs, greater structural integrity, and less production time result from a new electronic assembly encapsulation system developed by the U.S. Army Armament Research and Development Command. This project is reported in our article on page 24. Not only the electronics receives better support through the new method, but greater structural support is experienced also by the entire body assembly.

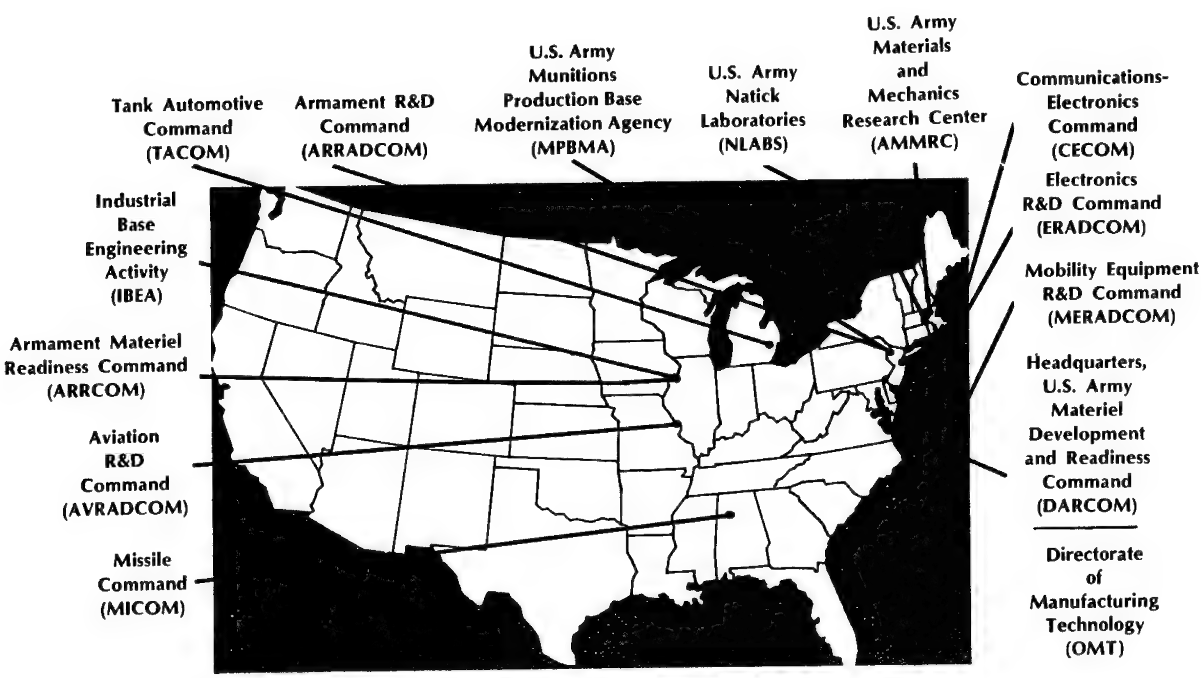
Sharply reduced production lead time is the result of a project by the Chemical Systems Laboratory of ARRADCOM, making large scale production of chemical agent alarm systems for our soldiers a faster reality in the event of a mobilization. The project could have incalculable effect on our military effectiveness if the need should ever be thrust upon us to counter chemical warfare tactics.

Enhancement of structure of mortar bodies and projectile preforms has been made possible by the application of squeeze casting, or "liquid metal forging", to their production by the U.S. Armament Research and Development Command's Large Caliber Weapon Systems Laboratory. Considerable savings in energy and dollars will transpire as a result of implementation of this new technology. Its applicability to other items is being considered.

Dramatic reductions in cost (8:1) and flow time (5:1) will be realized by implementation of a new inspection system developed by the U.S. Army Missile Command utilizing radiographics in lieu of photographic methods. The new technology will see application in the ROLAND missile production first, with further applications (and savings) forthcoming with other items—such as evaluation of composites.

It is always satisfying to hear of another publication picking up and using material from our Army ManTech Journal, and we have been told that the November, 1982 issue of the magazine of the Society of Manufacturing Engineers, **Manufacturing Engineering**, features a full article based on the Computer Assisted Planning articles carried in two previous issues of our Journal. The information from this breakthrough Army project is free to anyone desiring it by writing to the U.S. Army Missile Command, Manufacturing Technology, Building 5400, Redstone Arsenal, Alabama.

DARCOM Manufacturing Methods and Technology Community



ARMY AVIATION MANUFACTURING TECHNOLOGY CONFERENCE III

Bruce Park
Conference Coordinator

The Army Aviation Manufacturing Technology Conference III will be held in Williamsburg, Virginia, March 7-11, 1983. It is being sponsored by the U.S. Army Aviation Research and Development Command with support of the U.S. Army Materials and Mechanics Research Center, Directorate for Manufacturing Technology of the U.S. Army Materiel Development and Readiness Command, and the U.S. Army Industrial Base Engineering Activity. The American Helicopter Society is handling the Conference.

Conference Objectives and Guidelines

The purpose of the Conference is to reduce the cost of Aviation Systems by methodizing the selection of Manufacturing projects directed toward cost reduction. The ultimate objective is the development of a five year plan by identifying problem areas, obtaining suggested potential projects for solutions, and defining investment priorities based on savings to investment ratio. The most significant portion of the Conference will be the development of a list of recommended potential projects which the U.S. Army Aviation Research and Development Command will use as a basis for future investment in Manufacturing Technology. The Conference will be structured around five aviation systems functional group panels with the panel chairmen chosen from the aviation industry.

Unlike a seminar type conference, the Army Aviation Manufacturing Technology Conference is a highly structured working conference. Proposed projects will be requested in advance of the Conference. Proposals will be collected and published by panel area for review by the panels prior to the Conference as a means of stimulating even greater in-depth review and analysis. The Conference format will include initial presentations by each panel discussing state of the art, problem areas, opportunities, etc. Each panel will separately review proposed projects and prepare a prioritized list for their area of interest. Submitted projects will be analyzed in terms of return on investment and risk as well as noneconomic benefits such as reliability, maintainability, pollution, and safety.

Program Description

Scope. The basic goal of the Army Aviation MM&T Program is to make sure that the Army is able to acquire and maintain helicopters with optimum performance for a minimum affordable cost through the development and application of improved manufacturing technology.

To achieve this goal, two main areas of effort are performed under the scope of the Aviation MM&T program:

- Those efforts to **improve manufacturing** methods, undertaken primarily for cost (initial or life cycle) advantages
- Those efforts to achieve **producibility of components** developed for either cost or performance advantages.

Within these broad areas of effort, individual MM&T projects are conducted which of necessity encompass a wide range of design, material, structure and process related activities. A summary of the activities which may be undertaken during an MM&T project follows:

(1) Developing new/improved manufacturing processes.
(2) Solving production problems.
(3) Providing for the efficient use of automated design/manufacturing techniques.
(4) Developing in-process inspection techniques.
(5) Producing limited numbers of essential items for the purpose of scaling up to production methods shown feasible by laboratory techniques.
(6) Providing production engineering for facilities.
(7) Providing for the reduction of skilled manpower, critical materials, and/or critical machine tools.

Funding Increased

While there was slow growth in the AVRADCOM MM&T funding from the 1967 to 1978 time frame, there has been and will continue to be a sustained higher level of funding from 1983 to 1988. Twenty projects have been included in the FY 83-87 five year plan.

General Techniques for Generic Structures

Using Composite Materials In Bridging Systems

GAYLE D. PETERSON, writer/editor in the Public Affairs Office of the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), received her Bachelor of Journalism from the University of Missouri. She spent three years as a professional radio announcer before entering DARCOM's career intern program in 1976. She is a graduate of the Defense Information School's Public Affairs Officer Course and Newspaper Editor Course and is currently enrolled in graduate level courses in public relations at the American University. Miss Peterson has served as a newspaper and magazine editor and has written numerous feature articles for national and worldwide publication.

Finding new and improved ways of manufacturing a piece of equipment is often as important as the development of the item itself. The Marine and Bridge Laboratory at the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) is working on two manufacturing technology projects to produce bridging components made of lightweight structural composite materials.

Need Mandates New Techniques

The modern Army needs equipment with greater operational capabilities than ever before. This generally means that increasingly expensive and exotic materials with improved physical and mechanical properties must be incorporated into equipment design. How can these generally more expensive materials be exploited to provide for the increased capabilities without having the equipment cost escalate to the point where it is unaffordable?

One answer is to find low cost and low labor intensive manufacturing techniques which can reduce the overall fabricational cost. This is where MM&T comes into play. Lightweight structural composite materials—such as graphite/epoxy, Kevlar, and fiberglass/epoxy—fit into this category. They possess greater strength and stiffness at lower densities than even the most advanced aluminum alloys and show the promise of low manufacturing cost, since many textile processes requiring little skilled labor can be used.

An MM&T effort will take these textile methods and adapt them to cost effective means which are suitable for high load structural designs. But first, let's take a look at the Bridge Composite Program.

Producibility Engineering Applied

The obvious goals are to provide increased operational capabilities, such as higher load capacities and quicker launch/retrieval times, while decreasing weight and deflection. The procedure chosen to accomplish these goals was to replace selected bridge components with parts made of composite materials.

In order to accomplish this, a developmental bridge was chosen as the test bed and structural components selected which represented general classes of structural elements such as the bottom chord, webs, traversing beam, and bridge reinforcement. New components were designed and built using the proposed fabrication techniques.

Composites can be tailored to individual design requirements and fabrication techniques. An example of this tailoring would be the ability to lay more fibers parallel to the load (where they are needed) while reducing the

NOTE: These manufacturing technology projects that were conducted by the Marine Bridge Laboratorywerefunded by the U.S. Army Mobility R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MERADCOM Point of Contact for more information is Richard W. Helmke, (703) 664-5176.

number of fibers that are transverse to the primary loads.

This tailoring process has led to a unique combination of R&D and MM&T. Instead of the MM&T being incorporated after the design, R&D and MM&T are done together to produce an efficiently designed and fabricated component.

Specific Applications for Future

From this early work, it appears that composites are a viable material for bridging. Equipment fabricated with composite material will not only be economical to produce, it will also be lightweight, more transportable, have a higher load capacity, and be easy to repair in the field. Specific bridging areas being pursued for future development using composite materials include the heavy assault bridge, heavy dry support bridge, access/egress systems, and reinforcement systems—such as one for the medium girder bridge (MGB).

Now with this background let's examine two ongoing MM&T efforts. These are for the fabrication of a traversing beam and a tensile reinforcement element. A traversing beam is used to emplace or recover a bridge. When the program was initiated it was part of the Bridging for the 80's program. The all aluminum beam design weighs 110 pounds per linear foot and makes up 25 percent of the weight of the entire bridge structure. The laboratory designed an all composite beam which would weigh only 35 pounds per linear foot and could support more of the bridge load. The problem was how to mass produce it.

Current Application Tested

Incorporating manufacturing technology into the early stages of the development process would insure that the new type beam would be strong, light, and inexpensive to produce. Fiber Technology, Inc., of Provo, Utah, set up an assembly line to manufacture the beam components under MERADCOM's MM&T program. Under the test concept, fabrication of the beams was done in six steps. A specially designed, seven meter tubular winding mandrel (Figure 1) is wound with graphite epoxy in three different plys with each ply at a different angle. Continuous graphite loops called longos are next wound around steel spools. These longos are then laid on the top and bottom of this core in a staggered arrangement to form multifingered shear joints. Next the spacers, sandwich core, and slider tracks are placed on the winding mandrel and the entire piece is wound with several more layers of graphite epoxy. The mandrel is then removed, leaving a "box", which is placed in a mold and cured in an oven. Let's see how it works.

Graphite fiber is coated with epoxy resin and wound around an inflatable plastic "balloon" to form the core or "box" for the section. Meanwhile, another winding machine winds more fiber in three different plys around a

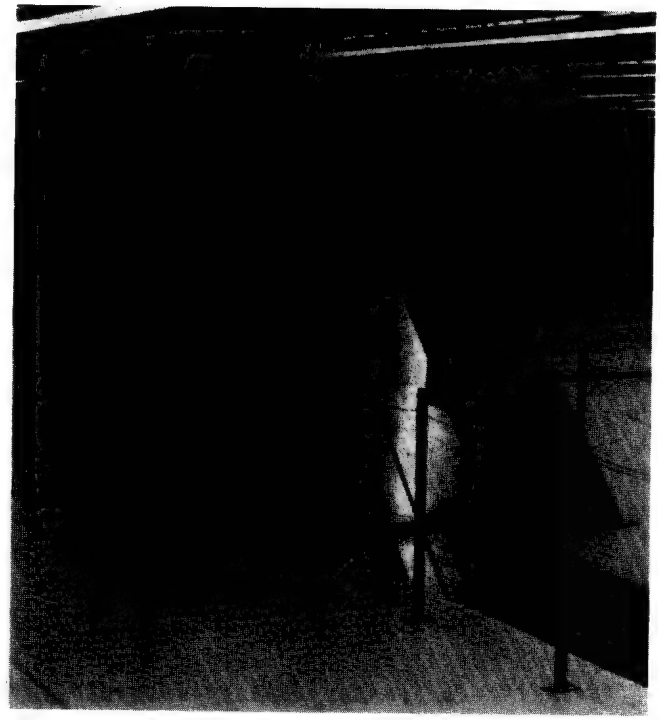


Figure 1

circular guide to form various widths of "yardgoods" which will be used to make the individual components of the section (Figure 2). The circular yardgoods are slit open and laid flat for cutting. This is done with a clincher press using different shaped dies for each piece (Figures 3 and 4). The cut pieces (Figure 5) have the texture and feel of a damp chamois skin. After they are cut they are stacked to form various thickness and groove patterns (Figure 6). These pieces are placed in a molding press which presses them together and heats them in order to form a semi-chardened, or B-staged, piece (Figures 7 and 8). These pieces are placed on the ends of the core to form shear joints and the entire section is then placed on a special vertical winding machine which winds long loops of graphite epoxy called longos between the fingers of the joint (Figure 9). The section is then wound with more graphite epoxy. Finally, slider tracks are added and the completed section is placed in a mold and cured in an oven (Figure 10).

Precision Winding Paramount

The winding process is critical. Not only does it enable the manufacturer to lay down different widths and plys of graphite epoxy in order to form the individual components of the structure, but precise control of the fiber tension as it is drawn from the individual spools insures a finished product which acts uniformly to support the bridge loads (Figure 11).

The end result of this highly automated process is a mass produced, close tolerance beam section which can be joined to other sections to create beams for different lengths of bridging (Figure 12).

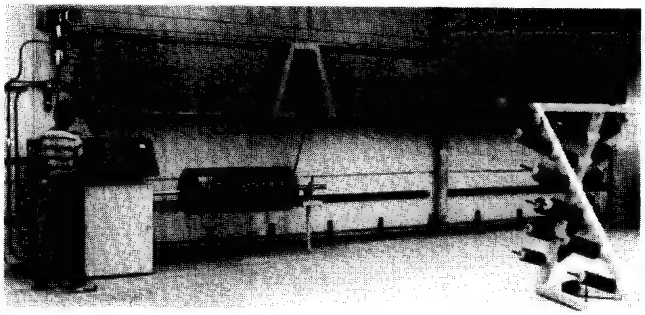


Figure 2

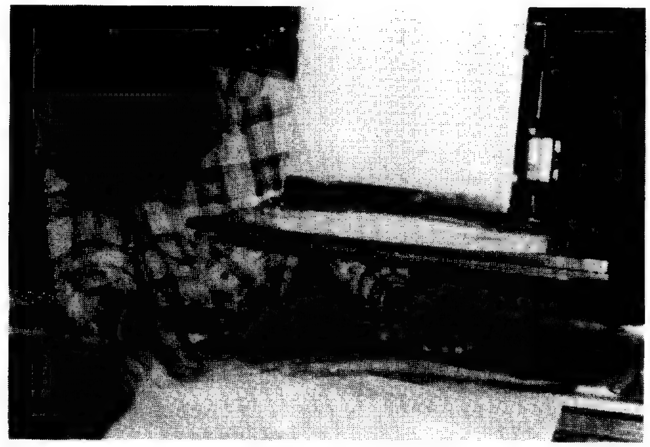


Figure 3

General Purpose Link Designed

A second MM&T effort that was initiated under the Bridging for 80's program pertains to a link reinforcement system made of composite materials for reinforcing long span bridges. The reinforcement element is a racetrack configuration (elongated loop much like the shape of a stretched rubber band) made of a low modulus graphite/epoxy composite covered with Kevlar. This element was designed to replace the steel reinforcement rods used in the Bridging for the 80's bridge structure, but the technology has application for other systems, such as reinforcing the medium girder bridge system. The steel rods weigh 180 pounds each and require three men to emplace them. The composite version will weigh less than 90 pounds and can be emplaced by two men in less time. It should be noted here that what has actually been designed is a general purpose tensile link and production process which could have many applications.

To produce this design the contractor, Fiber Materials Inc., of Biddeford, Maine, designed a system which combines wet filament winding with mass production. One rotating axis turns several winding mandrels like a crankshaft. Spools of graphite epoxy fiber are attached to the ends of each mandrel, along with a Kevlar channel which guides the fibers and will eventually become a protective cover. The mandrels are rotated while the fiber is laid in the channels much like a fishing reel. The elements are then vacuum bagged (air is drawn out) to consolidate the fibers and prepared for curing in an oven. This process enables many elements to be wound at one time reducing fabrication time and manpower. It is also energy efficient since several elements can be cured at one time, reducing oven preheat time.

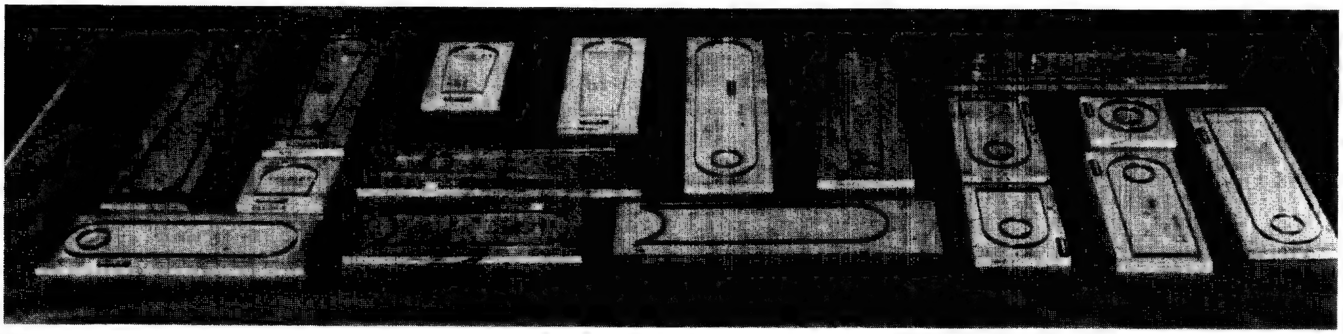


Figure 4

Figure 5

Universal Uses Possible

These programs are among MERADCOM's first efforts to develop viable methods and technology for incorporating composite materials into Army bridging systems. The process of the selective replacement of components produces designs which are common to specific classes of components; the traversing beam is common to any box beam element while the tensile reinforcement element is common to any tensile component such as tensile links and braces. These programs were valuable vehicles for the development of general manufacturing techniques to be used on generic structural elements. The first composite beam was delivered for testing in November, with more work to follow as the fabrication process is perfected. MM&T projects like these will insure that the Army's materiel acquisition agencies use the latest technology to meet the needs of the soldier now and in the future.

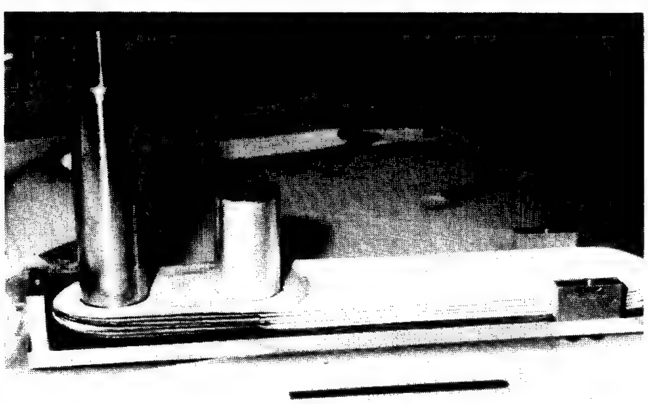


Figure 6

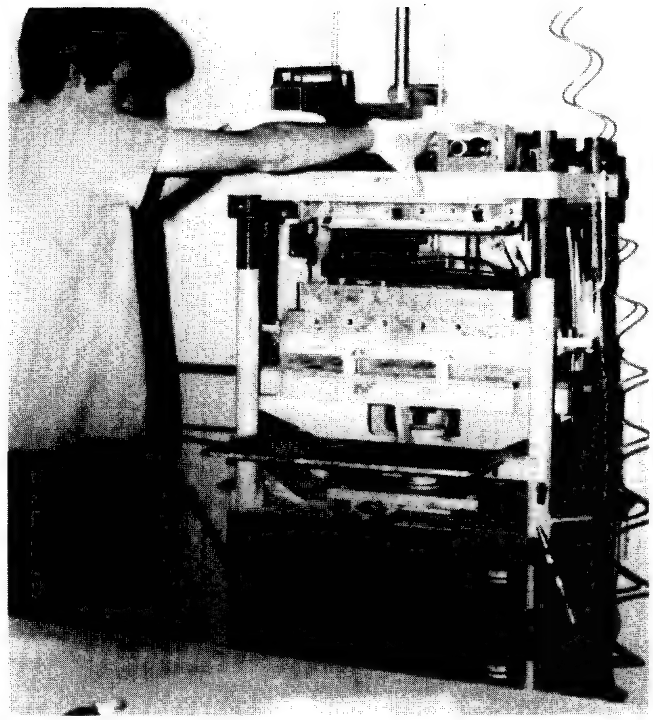


Figure 7

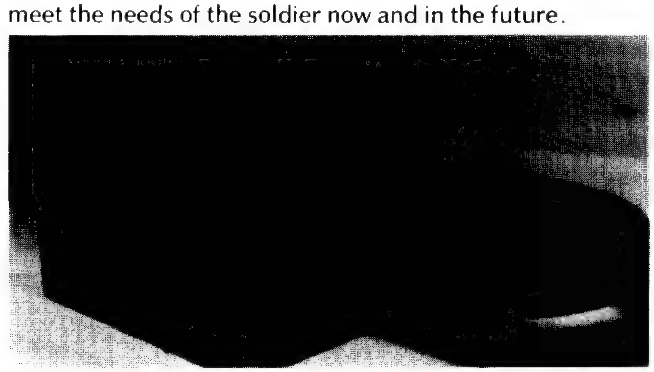


Figure 8

Editors Note: The products discussed here are not proposed for specific current bridges; however, the manufacturing methods and techniques developed under these programs are applicable to several bridge systems where only the overall size and capacities of the units will be modified.

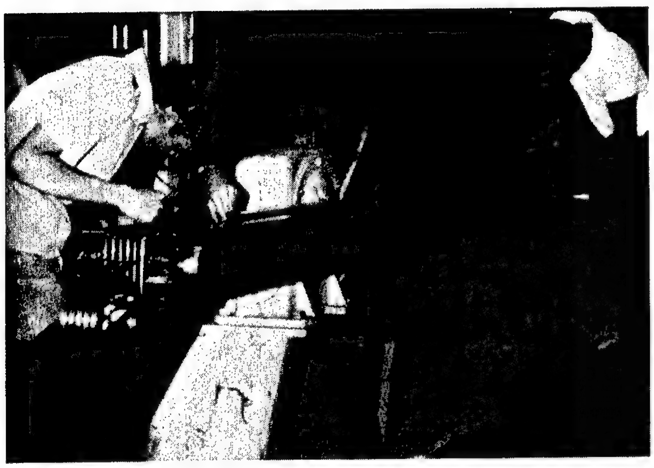


Figure 9

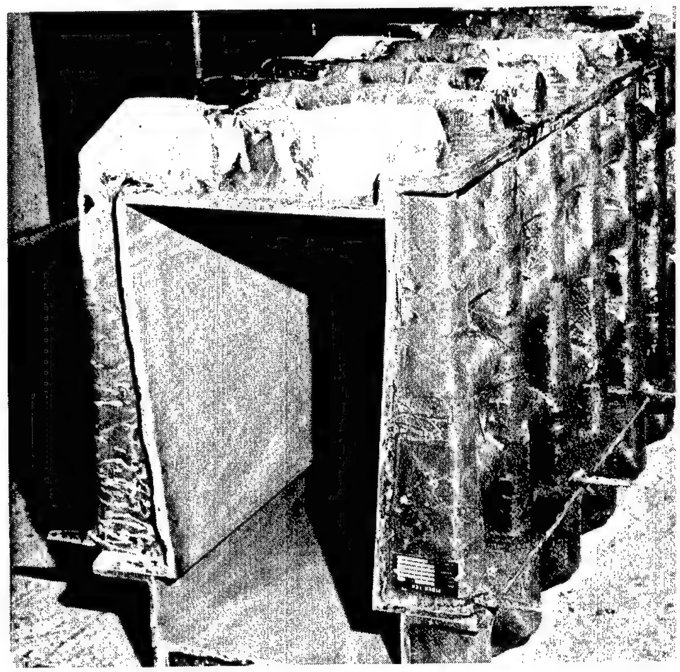


Figure 10

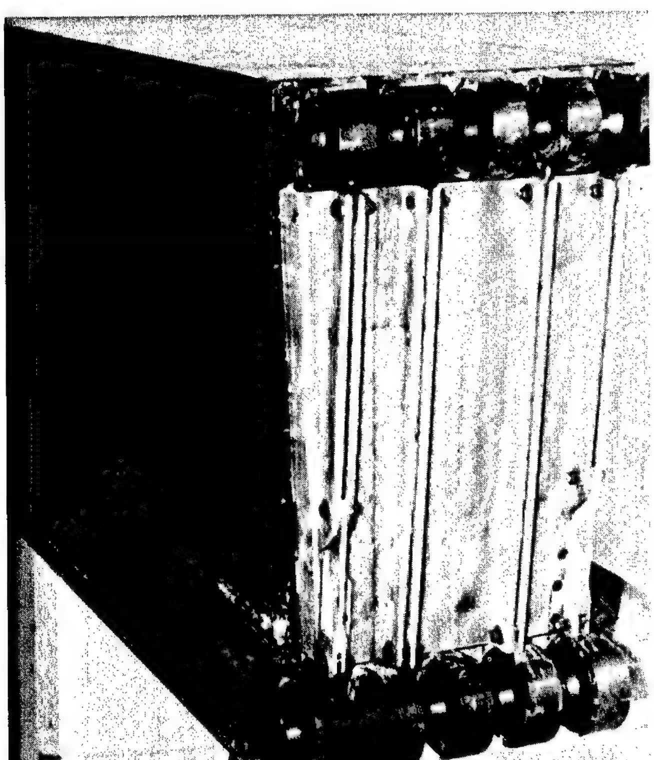


Figure 12

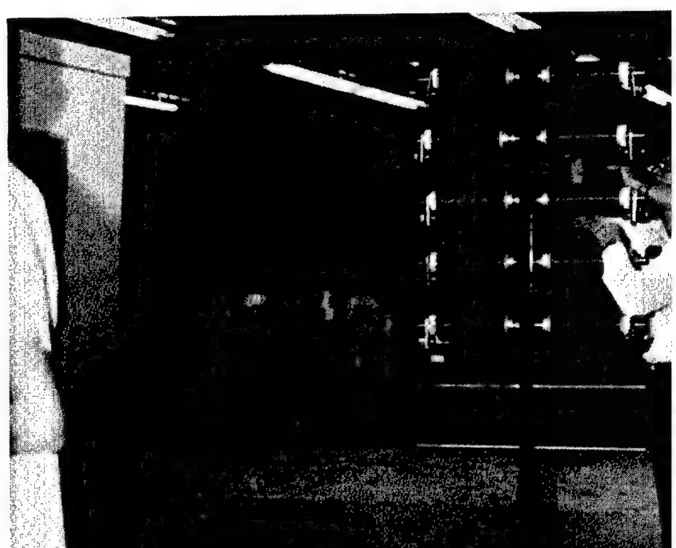


Figure 11

Installation Paid For in 1st Year

Central Lubricant Cooling System

By
Rocco S. DeMeo
Project Engineer
Benet Weapons Laboratory
Watervliet Arsenal, N. Y.

An unusual opportunity has become available to the U.S. Army Armament Research and Development Command following completion of a study by ARRADCOM's Benet Weapons Laboratory, Watervliet Arsenal, to determine a more economical way of using coolant oils for machine tools. The opportunity involves the installation of a new system that would totally pay for itself in savings in less than a year and then continue on into the future accumulating savings at a steady rate.

Currently, a variety of machine tools use identical water soluble coolants. Because these machines are used intermittently, lack of agitation allows a stagnation and consequent bacterial buildup. This bacterial buildup eventually destroys the coolant effectiveness and it has to be discarded. As the supply of coolant oil becomes more critical and its price continues to rise, it is no longer feasible to frequently discard the coolant.

Benet Weapons Laboratory undertook a study to solve this costly problem. The logical way to achieve conservation is through effective coolant control. While proper coolant control is difficult to maintain at many individual machine sumps, it can be successfully implemented at one central location.

A Cut Above the Rest

Cutting fluids are an important factor in the metal machining process and are perhaps the most neglected. Basically, they are divided into three categories—straight oil, water soluble oil, and synthetics. Due to their lower relative cost and good coolant and lubricating qualities, the water soluble oils are the most widely used. However, there are also disadvantages in using water solubles such as poor mix stability, short life, and high disposal costs. The functions of properly maintained cutting fluids are to cool the workpiece, reduce friction in cutting and grinding, extend tool life, protect the tools and workpiece from rust, and wash away chips.

For the coolant to perform these functions, it must maintain its chemical and biological stability and cleanliness. When destabilization occurs, the coolant will spoil and fail to provide some or all of the functions. As previously mentioned, these machines are used intermittently, and the lack of agitation coupled with the presence of tramp oil allows stagnation and a buildup of anaerobic bacteria. Eventually, this bacteria buildup will destroy the coolant. Its presence makes itself known by the offensive odor given off. When deterioration of the coolant occurs, it has to be discarded. Then the tank must be cleaned and recharged with fresh coolant. In addition to the high cost of materials and labor required for individual sump maintenance, the recurrence of contaminated coolants in the work area is associated with several manufacturing problems, such as:

- Loss of productivity due to the downtime required for coolant pumpout, sump cleaning, and recharging
- Skin irritation
- Loss of rust protection
- Creation of tramp oil (mineral oil) contamination, which introduces abrasives into the coolant and also creates a fire hazard
- Disposal problems.

NOTE: This manufacturing technology project that was conducted by the Benet Weapons Laboratory at Watervliet Arsenal was funded by the U.S. Army Armament R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Mr. Rocco S. DeMeo, (519) 266-5611.

Central Coolant System vs Individual Machine Sumps

This study was conducted to examine and compare the use of a central coolant distribution system versus individual machine sump maintenance. It was performed in the minor components manufacturing section because it employs a large number of small machine tools which are used intermittenly and consequently experience frequent coolant spoilage.

Many types of liquid clarification systems were investigated along with their advantages and limitations. The first one investigated was the gravity or settling tank. This is the most inexpensive of all the types considered but was rejected because of the large reservoir requirements to service the manufacturing section selected. The tank capacity has to be ten times the total gallons per minute "GPM" requirements of the machines. Also, this unit will not remove fine or floating particles.

The next system investigated was hydrocyclone clarifiers. Here, the fluid is pumped into the cyclone cell by means of an axial distributor. This spinning of the coolant within a cone generates a centrifugal force. This force is divided into the primary vortex near the wall which accelerates downward in a spiral movement. The restricting effect of the outlet nozzle generates a rising secondary vortex which operates in the same direction and leaves the cell via the clean fluid pipe. Solid particles with a higher density than the carrying fluid accumulate near the wall, travel downward with the primary vortex, and then are discharged with a small amount of fluid into a container. These cells may be employed singly or in multiples and are inexpensive to operate. However, they are not practical to use where chips, turnings, and other flaky particles might enter the cone and clog the outlet nozzle.

Tubular filtration also was examined but ruled out. This type of filter unit offers a fine degree of filtration because of advantages of positive filtration and higher pressures than with vacuum. However, this type of system requires a great deal of servicing and cannot be used where heavy or bulky swarf must be removed. Heavy or bulky swarf must be removed by prefiltering methods and not introduced into the tubular filters. Floating materials cannot be removed, as sludge removal takes place at the bottom of the filter. Most tubular filter systems do not incorporate automatic backwash cleaning cycles because of the added expense.

Of all of the systems investigated, the one that will serve best is the vacuum filtration type. By employing multiple filter units in one reservoir, high flow rates and high sludge removal rates can be handled. The cost of operating these units is low and the servicing procedure is relatively simple. The degree of filtration can be varied by employing various combinations of filter media, which are capable of cleaning down to 5 to 10 micron. Each filter unit can be fitted with an automatic cleaning or backwash mechanism.

The Central Coolant System

The proposed Central Coolant System is composed of the following items (Figure 1): a water deionizer, a liquid proportioner, a coolant makeup tank, a reservoir (main filter unit), a centrifuge, clean coolant feed lines, dirty coolant return lines, and controls and monitoring equipment.

Since water comprises 90-95 percent of water based cutting fluid mix, its quality is important to cutting fluid performance. The most economical treatment for providing the high quality water needed in a central coolant system is to remove most of the minerals through deionization. The liquid proportioner shall be a positive displacement, automatic proportioning and mixing pump capable of accurately blending, cutting, and grinding fluid concentrates with water. Mixing range shall be from 1 to 10 percent to water by volume. It will operate using water line pressures and shall be capable of automatically turning itself off when the supply of concentrate is exhausted. All working parts shall be metal.

The makeup tank will be constructed of standard No. 9 gage sheet steel with a holding capacity of 250 gallons. It should also have a hinged cover that may be made of No. 16 gage sheet steel. The cover shall be provided with handles and may be made of multiple sections for ease of access. The intake liquid level will be maintained by a float control mechanism which will activate the liquid proportioner pump, and the output to the main filter system will be controlled by a pump which in turn will be activated on demand by a float control in the clean coolant side of the filter system.

The main filter unit is housed in a reservoir containing 20,000 gallons of coolant. This reservoir is divided into two sections, 12,000 gallons for the coolant to be processed and 8000 gallons for the clean coolant. The clean coolant side is fitted with an overflow weir that will return excess clean coolant to the treatment side to prevent spillage. The filtering is accomplished by a vacuum chamber fitted with a long life (10 year) filter media. Exceptions to this occur when the element is damaged through accident or misuse. The solids are drawn to the filter media by vacuum or settle to the bottom of the tank and are removed by drag flights. The accumulated swarf or "Cake" is dislodged from the filter unit through periodic automatic backwash of the filter media. The dislodged accumulation fails to the bottom of the tank to be removed by the drag flights.

Also, the reservoir will be recessed into a pit at sufficient depth to allow for the installation of the floor flume at the proper pitch angle to return dirty coolant to the reservoir by gravity. The reservoir and supporting equipment will be located as near the center of the first floor of the building as possible to reduce supply restrictions and to minimize buildup of swarf in the return flumes.

To control tramp oil contamination of the water base cutting fluid, an automatic self cleaning or self dumping centrifuge will be installed in the system. The centrifuge must reduce the tramp oil level in the system to no more than 2 percent, depending on the rate of leakage. A centrifuge with a capacity to handle 650 gallons per hour is of sufficient size to service the system that is being proposed. The proposed centrifuge is semiportable, mounted on skids, and has its own controls that will allow it to be operated independently of the main filter control unit. The bowl and separator disks are made of stainless steel.

The main coolant feed lines for the first and second floor of the building will be suspended from the ceilings and be of sufficient diameter so as to provide a constant coolant flow of 30 psi at the furthermost laterals. The feed lines connected to the individual machine coolant nozzle will be flexible tubing and each line will be fitted with a shutoff valve. The return lines from the first floor machinery will be by means of floor flumes. The flumes are sheet metal troughs with rounded bottoms set into concrete lined trenches. The trenches will be of sufficient depth to allow the flumes to be pitched to maintain a constant coolant flow to the main reservoir. All flume trenches will be covered by steel diamond plate of sufficient thickness to carry normal shop traffic.

Computer Control

The entire filtration system will be controlled, monitored, and maintained by means of a programmable controller. The coolant distribution system will be divided into eight manufacturing sections, with each section to be activated by an electrically operated valve. This sectional control capability will give the operator the option of activating all or part of the coolant flow lines, depending upon the production requirements for the period. A cathode ray tube (CRT) with a colored raster display will interface with the programmable computer. This colored display will show which sections of the coolant distribution system are activated and functioning properly. Changing color displays will indicate impending problems or problem alert with audio warning. The return lines and flumes will have flow rate indicators that will help locate problem areas. To assist in maintaining the quality of coolant, the acidity level will be monitored automatically by a pH meter; and an automatic particle counter capable of measuring foreign matter in the coolant down to one micron will also be installed. The coolant quality will be recorded automatically at present times by an interfaced printer.

Installation Paid for the 1st Year

This central coolant system will service approximately 400 machines that use the same concentration of water soluble cutting fluids. In addition, to accommodate possible future changes in the layout of manufacturing equipment, all of the connections with individual machines will be by flexible hoses.

The installation of a central coolant system will cost more than $20,000 less than the projected annual savings! After the first year, when the system's cost is completely recovered, more than a quarter of a million dollars per year will be saved.

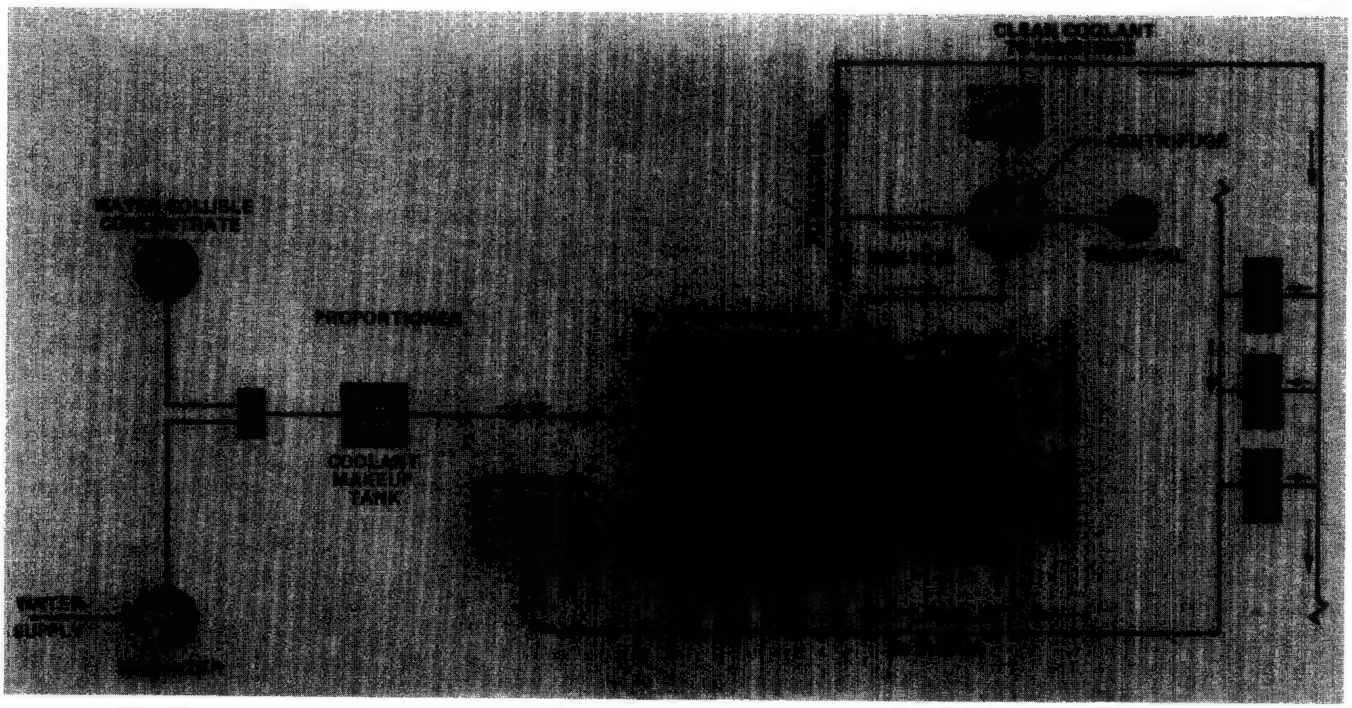


Figure 1

Brief Status Reports

Project 7370. Ring Wrap Composites. Large irregular shaped or long airfoil profiles present special problems when attempts are made to filament wind these configurations. A rotating ring structure containing filament spools and positioning eyes will be developed. It will orbit the stationary mandrel dispensing and positioning the filament material. For additional information, contact J. Pratcher, AVRADCOM, (314) 263-1625.

Project 7371. Integrated Blade Inspection System (IBIS). Inspection of turbine engine blades and vanes necessitates high accuracy. The effort is time consuming and susceptible to error. This project will improve the infrared, X-ray, and infrared thermography inspection modules by increasing reliability, repeatability, and sensitivity. Also, inspection costs will be reduced. Work continues to update manipulation software for more efficient blade handling. A method for positioning blade grippers to a reference point during the inspection scan is being developed. For additional information, contact B. Park, AVRADCOM, (314) 263-1625.

Project 7376. Auto Inspection and Precision Grinding of SB Gears. Current manufacturing methods for spiral bevel gears is labor intensive, requiring contact pattern checks with expensive master mating gears. The pattern shifts with a change in torque and temperature, and as a result the tooth form experiences great stress. This project will develop an automated production process of grinding spiral bevel gears by tape controlled machines, based on a coordinate system made possible by a partial non-involute tooth form. For additional information, contact D. Pauze, AVRADCOM, (314) 263-1625.

Project 7382. Low Cost Composite Main Rotor Blade for the UH-60A. Manufacturing technology for cocuring glass and graphite filament wound main rotor blades has not been established for the production environment. This project will develop filament winding technology for fabricating D spars through optimized winding of wet filaments. For additional information, contact N. Calapodas, AVRADCOM, (314) 263-5732.

Project 8246. Improved Finishing of Gas Check Seats. Machining of gas check seats is a precision process involving grinding and lapping of a critical area of the cannon which results in 30 to 50 percent rework to pass contact gage requirements. This project will apply more precise alignment of finishing equipment and eliminate the machining facility which tends to induce eccentricity. The gauging system will also be reviewed. For additional information, contact C. LaRoss, ARRCOM, (309) 794-5611.

Project 7243. Machining Operation on Kevlar Laminated Constructions. Present methods of machining Kevlar laminates tend to cause delamination and excessive fuzzing or fraying of the cut edges. This necessitates the use of time consuming and repetitive techniques to achieve acceptable machined surfaces. Experience indicates that recently developed advanced cutting techniques, including high pressure water jet and conventional diamond tools have the ability to effectively machine Kevlar with increased tool life. The technology/literature and organization survey indicated that the water jet offers the best potential for cutting thin laminates (1/8 inch). For additional information, contact C. Stuhlman, AVRADCOM, (314) 263-5732.

Project 7291. Titanium Powder Metal Compressor Impeller. When complex configurations such as centrifugal impellers and compressor rotors are utilized in gas turbine engines, typically high manufacturing costs are encountered. This project will develop overall process controls capable of reproducibly producing 100% dense parts with tensile and fatigue strengths equal to those of high quality titanium forgings. For additional information, contact J. Lane, AVRADCOM, (314) 263-2771.

Project 7300. Improved Low Cycle Fatigue Cast Rotors. Integrally cast turbine engine rotors have been shown to be cost effective. However, investment casting results in large grain sizes in the disk region, which reduces fatigue life compared with wrought material. This project will define casting and heat treat parameters and finalize the manufacturing technology for establishing fine grained cast rotor production utilizing grain refinement techniques. For additional information, contact J. Lane, AVRADCOM, (314) 263-2771.

Project 7298. Evaluation of High Temperature Carburizing. Gear Carburizing is presently carried out with a relatively slow endothermic process typically at 1700 F, which requires postheat treat removal of the decarburized layer. This project will reduce processing time by increasing the operating capacity. Also, investigation of vacuum carburizing and hardening of various gear configurations in order to produce a more uniform carbon profile of gear teeth. For additional information, contact P. Fopiano, AVRADCOM, (314) 263-3327.

Project 7340. Composite Main Rotor Blade. Current production composite blade programs have not been oriented toward optimizing manufacturing techniques/processes related to blade configurations, fabrication methods, and improved structural reliability. Improved methods will include soft inflatable mandrels, in crease in fiber band width, improved matrix control procedures, balanced shell tooling, and net shape winding. Fatigue tests were resumed with a corrected test procedure and lower frequency with successful results. Flight tests revealed problem area in the blade design. For additional information, contact J. Tutka, AVRADCOM, (314) 263-1625.

Project 7341. Structural Composites Fabrication Guide. The need exists to document industry experience in composites so that cost and manufacturing comparisons can be made. The guide will provide information in a synergistic fashion to provide production analysis and process/cost interrelationships and promote a thorough manufacturing interface. For additional information, contact D. Haugan, AVRADCOM, (314) 263-1625.

Project 7342. Pultrusion of Honeycomb Sandwich Panels. Fabrication of honeycomb sandwich panels is labor intensive and face-to-core bonding often takes two cure operations. Pultrusion can be used for continuous production, but commercial parameters and tooling are not suitable for military use. This project will establish technology necessary for production pultrusion of sandwich structures—including beams—for use in composite airframes. Parameters will be generated and optimized for pultruding military quality flooring. For additional information, contact N. Tessier, AVRADCOM, (314) 263-3712.

Project 7319. Multi-Legend Display Switch (MDL/S). Experimental versions are expensive and difficult to manufacture because the mounting of the commercially available electronics display chips and switches must be done by hand to obtain proper ruggedness and operation of the structure. This project will make the MLD/S a manufacturable item so that it can be made routinely available for incorporation in avionic systems. It will establish the manufacturing techniques to properly mount, align, and fabricate militarized displays and switches. For additional information, contact Brad Gurman, AVRADCOM, (314) 263-4201.

Project 7202. Thermoplastics for Helicopter Secondary Structures. Forming fiber reinforced thermoplastic components into complex multicurved structural configurations with uniform fiber distribution, minimum warpage, and acceptable dimensional tolerances has not been established for aircraft components. This effort will establish techniques, special tooling, and processes to form such components with vacuum or air pressure assist methods. In addition, techniques to restrain the matrix and fiber layers in position during heatup cycle will be established. Process procedures were established. Fabrication of the inner door skin resulted in unacceptable wrinkling. Subsequent fabrication with alternate materials also resulted in wrinkling. For additional information, contact R. Rodgers, AVRADCOM, (314) 263-2975.

Project 1042. Production of Composite Radome Structures. The basic material for composite radomes is expensive ($25/lb). The fabrication procedures for producing the radome structure are complex and expensive, with some procedures being proprietary. This project will establish fiberglass reinforced Teflon as a replacement for the current dual wall bonded proprietary material (Durviod). Optimum processing will be selected based on mechanical properties and sled test results and will be scaled up. For additional information, contact Mr. Bobby Austin, MICOM, (205) 876-2147.

Project 7322. Low Cost Transpiration Cooled Combustor Liner. Combustor liners of advanced gas turbine engines are required to survive using less cooling airflow than heretofore available. State of the art transpiration cooled liners can meet the requirements, but manufacturing processes are not cost effective. This project will refine a low cost manufacturing technique to form the necessary complex shapes and cooling passages. The process will be usable with common combustor liner alloys to be consistent with the low cost being pursued. Joining will also be refined. For additional information, contact R. Bolton, AVRADCOM, (314) 263-3977.

Project 7338. Composite Tail Section. The potential cost and weight advantages of composites for airframe components have not been fully demonstrated due to fabrication limitations related to configuration restraints—for example, inplace winding, complex contours, and co-curing. Experimental fabrication technology, developed under an R&D effort, will be reviewed and improved. Automated manufacturing procedures will be established for the YAH-64 helicopter tail section; filament winding is the primary technology involved. For additional information, contact J. Tutka, AVRADCOM, (314) 263-1625.

Project 7055. Ultrasonic Welding of Helicoptor Fuselage Structures. In joining doubly panelled components of structures such as doors, the parts being joined must be formed to match almost perfectly in order to permit reliable bonding. This project will develop techniques to ultrasonically weld the structures, eliminating the requirements for adhesive bonding agents and vacuum bagging. The contract was awarded but the project has been delayed because the subcontractor could not produce quality ultrasonic welds. For additional information, contact F. Rodgers, AVRADCOM, (314) 263-2975.

Project 7086. Abradable Seals for Compressor Blade Tip Applications. Extra blade tip clearance is allowed in helicopter engines to prevent tip rubbing, and this degrades performance. This project will develop the manufacturing process to obtain replaceable abradable seals built into the turbine shrouds. Feltmetal (FM 515B) abradable seals were attached to simulated engine hardware rings and an Allison T-63 compressor front diffuser assembly using inhibited chem-brase cement. The seal was stripped and reapplied. For additional information, contact M. Levy, AVRADCOM, (314) 263-3331.

Project 7091. Fabrication of Aircraft Components Using Hybrid Pultrusion. Current metal extrusions used in Army aircraft for such applications as landing gear/skid assemblies are characterized by fatigue failure and high cost. This project will develop the pultrusion process for incorporating hybrid materials in composite structures, resulting in a combination of the best properties of several materials, low manufacturing cost, and ease of fabrication. A new vinyl ester resin system was selected for the door track. The resin can be sealed and stored at room temperature in a matured state for an extended period of time. Baseline pultrusion data has been started at AMMRC on this resin. For additional information, contact N. Tessier, AVRADCOM, (314) 263-3172.

Project 7108. Manufacturing Techniques for Transmission Shaft Seals. Current helicopter transmission seals are susceptible to wear and thermal degradation, resulting in leakage of transmission oil and frequent seal replacement. Integral molding of a hybrid elastomeric segmented carbon ring seal combines the compliance of elastomeric tip seals with the wear resistance and temperature tolerance of mechanical carbon seals. Carbon rings and garter springs have been fabricated, but problems with variable shrinkage rates in the elastomeric molding process have been experienced. The test heads and the inspection and assembly fixtures are ready for use. For additional information, contact D. Brewe, AVRADCOM, (314) 263-1625.

Project 7113. Composite Rear Fuselage Manufacturing Technology. Application of composite materials to airframe fuselage components possesses a large potential for cost and weight savings. However, production manufacturing processes have not been established for large, full-scale compound curvature components. This project will establish technology for fabricating molded composite rear fuselage structures, with emphasis on Blackhawk. Low cost tooling, forming modules, and co-curing processes will be developed to insure high repeatability and integrity. For additional information, contact D. Orlino, AVRADCOM, (314) 263-2875.

Project 7155. Cost Effective Manufacturing Methods for Helicopter Gears. Demand in helicopter operation for greater reliability of high performance gears at lower cost has required that improved processing and evaluation techniques be instituted. This project will address the total gear manufacturing process, integrating available nondestructive inspection procedures and replacing individual tooth grinding with a combination of ausrolling and a final rotary tooth finishing procedure. Detailed drawings of gear roller parts are completed. The load frame was designed and construction was started. Design of rough tooth form is completed. For additional information, contact E. Kinas, AVRADCOM, (314) 263-3578.

Project 7156. Ultrasonically Assisted Machining for Superalloys. Many helicopter parts are expensive to machine. This project will employ ultrasonics to assist processing of hard to machine components. Ultrasonic equipment previously developed was upgraded during this reporting period by improving tool retention, developing an operation interlock, and improving control and instrumentation. For additional information, contact A. Ayvazian, AVRADCOM, (314) 263-3234.

Project 7144. Turbine Engine Nozzle In-Process Inspection. Assembled turbine nozzles need inspection and checking for blockage and air flow volume. This project will develop and use an automatic in-process nondestructive test procedure for checking nozzles for obstructions and adequate air flow. For additional information, contact P. Rolston, AVRAD—COM (314) 263-3555.

Project 7183. Semi-Auto Composite Manufacturing System for Fuselage Secondary Structures. Helicopter fuselage structures have high manufacturing cost due to high part count and high assembly costs. Methods of composite fabrication have been investigated, but hand operations result in high labor costs. This project will use equipment and techniques developed by industry in support of Air Force composite component programs. The selected system will be updated and modified to accommodate helicopter components, which are more complex and have more curvature than Air Force components. An acquisition cost analysis report covering projected acquisition costs and cost tradeoffs between prototype and composite doors was completed. For additional information, contact E. Dean, AVRADCOM, (314) 263-3822.

Project 7191. Fabrication of Integral Rotors by Joining. Current gas turbine rotors are either integrally cast or the blades and disks are separate units. The blisk concept does not permit optimum mechanical properties of the unit and the other method requires complex and expensive machining. A bonded blade and disk is feasible and will reduce the major machining requirements, stress concentrations, and size and weight constraints on the design. This also allows material selection to be based on performance rather than joining capacity. For additional information, contact J. Lane, AVRADCOM, (314) 263-2771.

Project 7143. Manufacturing of Spray Abradable Gas Path Seal System. Metallic systems currently used in high pressure turbine seals degrade due to erosion, corrosion, and adverse rub behavior, resulting in increased clearances over the turbine blade tips and loss of engine performance. Extensive R&D work has been performed under NASA, ARMY, and NAVY contracts and industrial R&D to develop various ceramic seal material systems. Manufacturing process parameters will be established for plasma sprayed zirconium oxide seal components. For additional information, contact R. Bill, AVRADCOM, (314) 263-1625.

Project 7339. Filament Wound Composite Flexbeam Tail Rotor. Filament winding from a solid flexbeam to an open spar section, winding to net shape, improved resin control and tolerance control must be obtained to enhance the cost effectiveness of flexbeam tail rotors. Techniques will be developed for continuous filament winding from open to closed sections, winding net contour shape, optimizing tolerance control with improved tooling, and improved resin control to ensure minimum weight components. Tail rotors have been fabricated. The blades displayed good appearance and are being nondestructively tested. In the ground-air-ground fatigue test and the static ultimate test the rotor specimens failed. Redesign of the blade is being contemplated and reconfiguration of the pitch case and the case and flexbeam interface was accomplished. For additional information, contact D. Haugan, AVRADCOM, (314) 263-1625.

Project 7119. Nondestructive Evaluation Techniques for Composite Structures. Implementation of composite structures in Army aircraft is dependent upon the ability to detect and evaluate defects. This project will establish a viable and comprehensive in-process inspection program for nondestructive inspection of composite structures. A contract was let to University College of North Wales to fabricate piezoelectric polymer acoustic emission sensors. These sensors should have wide application for inspection/testing of composite structures. For additional information, contact R. Shuford, AVRAD—COM (314) 263-1625.

Project 8208. Material Handling. A study made on the 105 mm M68 gun tube production line revealed 12% of the time to produce the tube was "consumed in moving the tube about" and another 20% of the manufacturing time was spent in making the tube ready and taking the tube down from the machines. One method to reduce the handling time and terminal (positioning and removing) time would be to develop new equipment for positioning, lifting, and transferring of gun tubes and components. For additional information, contact R. Neinhart, ARRCOM, (309) 794-5737.

Project 8209. Pilot Production of Gradient Index Optics. Gradient optics, where the index of the glass is sequentially varied to obtain designed optical characteristics, is far more desirable than those currently used—forming a curve on the glass surface. This project will establish—subsequent to the introduction and development of gradient optics to military use—a pilot production facility to manufacture gradient optics at a required rate. A contract with the University of Rochester will scale up ion diffusion techniques for axial gradient index blanks. They will then be ground and polished into lenses and proved in a sight. For additional information, contact S. Kopacz, ARRCOM, (309) 794-2873.

Project 8047. Pass Thru Steady Rests for Tube Turning. Roller rests provide necessary support for gun tube turning but do not allow full length turning in one setup. Present method is to use two lathes with two setups or a lathe with two carriages. A pass thru rest will allow the carriage to move from one supported area of the tube to the other without disturbing the setup. The design will be applicable to currently available equipment but will have even greater impact on new equipment acquisitions. Engineering requirements for established hydraulic pressure to safely support and retain various gun tubes for exterior turning operations have been completed. Designs have been incorporated into a procurement specifications package. For additional information, contact J. Rodd, ARRCOM, (309) 794-5611.

Project 8048. Improved Inspection Techniques for Ingots and Preforms for Rotary Forging. The current technique of inspecting ingots is time consuming and prone to error. Each ingot or preform must satisfy an internal soundness requirement. Ultrasonic inspection is necessary. Automatic ultrasonic techniques will be developed to allow more rapid and accurate inspection. Evaluation contracts were awarded to three contractors. Each contractor states they had the capability to detect flaws in accordance with the performance criteria. The procurement request for the ultrasonic equipment has been forwarded. For additional information, contact V. Colangelo, ARRCOM, (309) 794-5517.

Project 8049. Manufacturing Processes Energy Conservation Program. As the price of utilities and fuels continue to increase, the possibility of curtailment in utilities during the winter months increases. Conscientious energy conservation efforts are required. A project to analyze present energy consumption and design a complete energy recovery system for manufacturing facilities and processes is the only solution to the problem. An energy audit of about 75% of the machinery engaged in the manufacturing data has been furnished to the operations directorate so replacements can be made with more efficient equipment. For additional information, contact P. Thornton, ARRCOM, (309) 794-4129.

Project 8035. Coating Tube Support Sleeves With Bearing Materials. Metallized coatings on support sleeves for gun mounts are brittle and lack bond strength. This project will provide induction/arc inert gas methods to coat sleeves with bearing materials. Steel test plates were clad with Al-Bronze using the gas metal arc welding process. Wear and friction tests showed improved wear resistance. Five M174 recoil mechanism pistons were clad with Al-Bronze. Destructive tests on two and live firing tests on three were conducted. The piston was considered in excellent condition for additional testing. For additional information, contact M. Solanki, ARRCOM, (309) 794-5965.

Project 8036. Weapon Aiming System for the 6-DOF Simulator. The existing physical simulation facility for evaluation and testing of weapons, stabilization, and fire control systems is not capable of fully testing these systems because the present aiming system is inadequate for large amplitude motions. This project will develop a weapon aiming system in which the gunner's line of sight is independent of hull motions induced by the simulator and which provides a remote control and display capability to the gunner. The initial work was the selection of a suitable television camera for mounting on the weapon system. This camera is a high shock resistant camera that will be mounted on the gun. This will allow the gunner to verify that the weapon aim is the same as his line of sight. For additional information, contact R. Radkiewicz, ARRCOM, (309) 794-6868.

Project 8043. Improve Machining Procedures for Dovetails. Close tolerance dovetails are required to assemble recoil rails on large caliber weapons. Extreme care is required when milling to avoid oversize cutting. This project will develop machining and tooling for machining. Dovetails in lieu of milling presently are used because of extremely close tolerances. Broaching, once developed, should improve quality output and reduce time; size control would be built into the tooling. Milling and broaching were considered as potential solutions. The machine specification for a bed type duplex milling machine with traveling columns has been completed. For additional information, contact G. Conlon, ARRCOM, (309) 794-5611.

Project 7200. Composite Engine Inlet Particle Separator. Currently, fabrication of the T700 inlet particle separator (IPS) involves machining of castings and forgings and the joining of these parts by welding and brazing. This is costly in terms of both material and labor. This project will establish a new process to fabricate the IPS from injection molded thermoplastic composite combined with high modulus, high strength thermosetting composite (graphite-polyimide). This will provide weight and monetary savings. For additional information, contact D. Cale, AVRADCOM, (314) 263-2771.

Project 8136. Improve Impulse Programmer for Hydraulic Simulator. Undesirable shock and vibration in tests of certain recoil mechanisms limit the extent of testing that can be accommodated on the hydraulic artillery test simulator. Design and manufacture improved impulse programmers to get better simulated firing that will be more effective for a greater number of weapons. For additional information, contact D. White, ARRCOM, (309) 794-4667.

Project 8151. Portable Engraving System. Currently, the component identification legend is stamped by hammer and individual alphanumeric stamps. This is a time consuming process with no depth control and can present a safety hazard to personnel. This project will provide a programmable data engraving system to relieve the operator of the fatigue and hazard of hand stamping. This will result in more uniform spacing and depth control and reduce both time and cost. For additional information, contact V. Montuori, ARRCOM, (309) 794-5507.

Project 8152. Improved Anode Straightness for Chromium Plating. Anode straighteness and rigidity are important for maximum and uniform radial distribution of current. A solid copper rod is presently used. Although anodes are made and preserved as carefully as possible, straightness is a recurring problem. This project will use in the copper anodes a commercially available composite rod made of unidirectional graphitic filaments in a suitable matrix. The specific strength will be 33 times higher and the specific modulus nine times higher than copper. For additional information, contact T. Pochily, ARRCOM, (309) 794-5717.

Project 7285. Cast Titanium Impeller for Turbine Engine. Current centrifugal compressor impellers are fabricated by machining the flowpath and blade surfaces from a forging. This results in a substantial loss of material and expensive machining operations. This project will establish the fabrication of titanium compressor impellers by casting and hot isostatic pressing (HIP). This method will reduce fabrication costs by 40 percent. Industrial R&D conducted by gas turbine engine manufacturers has demonstrated feasability. Detroit Diesel Allison has completed the evaluation of titanium castings. Solar Turbines has completed the effort evaluating mold modifications and alternate HIP/chem mill and heat treat procedures using castings from PCC and TiTech. For additional information, contact M. Galvas, AVRADCOM, (314) 263-2771.

Project 7286. Superalloy Powder Production for Turbine Components. With the commitment of gas turbine engine manufacturers to the production of engine hardware from superalloy powder, the need to improve powder cleanliness has been recognized. Reducing the level of nonmetallic inclusions and thermally induced porosity (TIP) will increase the yield of useful powder and permit higher design limits. Impurities will be reduced at all possible stages in the process, beginning with ingot melt. Probable sources of contaminants have been identified and corrective action is being taken. Work in the area of dynamic outgassing is being expanded. A method for hafnium addition in the electron beam remelting of ingots has been defined. For additional information, contact S. Isserow, AVRADCOM, (314) 263-3504.

Project 1050. Low Cost Braided Rocket Motor Components. Rocket motor costs to meet design-to-cost production goals have dictated reevaluation of materials and processes. Missile cases comprise 1/2 of propulsion system cost. Emphasis must be placed on establishing new component manufacturing processes. Optimize the production procedures and rates for integrally braided case/nozzle components to provide production engineering data essential to future motor component requirements. A contract was initiated and placed with McDonnel Douglas Astronautics Company. The optimization of raw material and preparation of the braiding mandrel has been initiated. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 7199. Surface Hardening of Gears, Bearings, and Seals by Lasers. Case carburizing is expensive, requiring much energy, also quenching dies and final grinding. This new method will reduce costs by reducing the energy required to heat treat, eliminate the quenching process, and provide the potential for eliminating final grind. Additional gear specimens have been laser treated. Problems include the occurrence of back tempering of the hardened flanks; also the case thickness at the ends of the teeth, which is less than required. Efforts were made to improve directional control and focus of the laser beam and to eliminate in-transit blooming caused by contamination of ambient air. Back tempering and nonuniform case depth problems still exist. Near term solutions are expected. For additional information, contact R. Mulliken, AVRADCOM, (314) 263-2771.

Project 3023. Tubular Plasma Panel. Present display device for TACFIRE has too small an active area and insufficient interactive and map capability. A tubular plasma panel can be used but is high in cost due to extensive labor in parts, inspection, assembly, and final inspection. Efficient manufacturing methods and techniques will be developed to produce reliable plasma panel displays. These will include automatic methods for spacer insertion and electrode and dielectric depositions as well as the incorporation of in-line processing. Fixtures for holding the glass plates for automated cleaning and for exposure and sputtering have been manufactured. Sample plates have been processed thru the automated chamber. A test set and exerciser has been assembled. For additional information, contact M. Crost, ERADCOM, (201) 544-5152.

Project 7288. Optimal Curing Condition for Process Fiber Reinforced Composites. Current methods of curing composites are based on empirical determination of required processing conditions. A trial and error procedure is followed until the manufacturer is reasonably satisfied with mechanical properties. By developing and employing improved methods of determining required processing conditions for composites, time and productivity can be improved in the mold. Composite laminates of glass/epoxy prepregs have been laid up and cured using autoclave, compression press, and microwave curing techniques in an effort to alter cure temperatures and times for achieving optimal cure using lowest energy consumption. For additional information, contact D. Granville, AVRADCOM, (314) 263-3172.

Project 5041. Millimeter Wave Mixers and Arrays. Low noise ruggedized reproducible mixers are needed for receivers for radar electronic warfare terminal homing and missile guidance. In situ construction and design will provide reproducible units at frequencies from 40 gHz up to 600 gHz. New technologies to be developed include electron beam lithography and computer control of materials growth. A contractor will establish a high yield method for making millimeter wave Schottky diodes for radar and communications systems. Computer control, ion implantation, and electron beam lithography will be used for precision material growth and doping. For additional information, contact S. Dixon, ERADCOM, (201) 544-4983.

Project 1041. Large Scale Integration (LSI) Fabrication Improvement. The yield of custom designed large scale integrated circuits for Copperhead is low (1-2%) because of mask manufacture and alignment problems, also semiconductor diffusion material and process control problems. This project will use fine line photolithographic techniques to make better masks. In process measurement and control of the semiconductor manufacturing processes will be utilized. For additional information, contact R. Wooten, MICOM, (205)876-8487.

Project 7238. Precision Forged Aluminum Powder Metallurgy. Many helicopter components are made from aluminum alloy forgings. These generally require a large number of manufacturing operations and low mechanical properties. This project will develop technology for reducing the number of manufacturing steps and increasing properties and performance of the components. Powder production, vacuum system construction, workability analysis, and process optimization was completed. Mechanical property tests are nearly complete. For additional information, contact M. Kumar, AVRADCOM, (314) 263-5816.

Project 7240. Machining Methods for ESR 4340 Steel for Helicopter Applications. Many critical helicopter parts require high ballistic tolerance characteristics. These components are being fabricated from ESR 4340 steel. However, the machining of this new material is not clearly defined and therefore is overly expensive. Machining methods will be investigated to establish the techniques necessary to efficiently fabricate components from ESR 4340. Both conventional and unconventional approaches will be pursued. For additional information, contact A. Ayvazian, AVRADCOM, (314) 263-3234.

Project 7241. Hot Isostatic Pressing of Titanium Castings. The current method of manufacturing rotor hubs results in excessive use of materials and machining. The current forged hub is a long lead time item. This project will establish the manufacturing process for hot isostatic pressing (HIP) of a cast Blackhawk titanium rotor hub. The required material properties are attainable and a cost savings of 36 percent is expected. Four rotor hubs cast from revert material have been poured. Processing of the last hub is near completion Ultrasonic testing has been completed and a final report written. For additional information, contact F. Hodi, AVRADCOM, (314) 263-3475.

Project 7990. Improved Fabrication and Repair of Anodes. The purchase of new or the repair of anodes is expensive and time consuming. Currently used cladding melted on lead is inferior to electrodeposited lead because of variations of thickness and oxide inclusions. An electrodeposition system capable of depositing lead will enable fabrication and repair of anodes in considerably less time than now required and at a lower cost. The design of the lead plating facility has been completed and all drawings and layouts have been finalized. The anode has been fabricated. The work for the plating assembly has been issued. For additional information, contact T. Pochily, ARRCOM, (309) 794-5717.

Project 8024. High Speed Abrasive Belt Grinding. Slide surface diameter and finish is presently produced on cylindrical grinding machines using abrasive wheels. The time it takes for this operation can be significantly reduced. Abrasive belt grinding depending on its application has metal removal rates which can exceed milling or grinding, at the same time producing excellent tolerances and surface finish. The specification was completed and a two step formally advertised procurement process is under way. For additional information, contact R. Meinhart, ARRCOM, (309) 794-5737.

Project 8025. Electronic Profile Readout Gage for Powder Chambers. Powder chamber size is checked by 4-6 flush pin gages, each weighing about 35 lb. From each check, machine adjustments must be made to machine the chamber to required specifications. Using new proximity sensing devices, one light weight gage would replace the 4-6 present gages. It would provide a signal for digital readout and for tool control in the latter phase of the project. Several gaging manufacturers of both contacting and noncontacting type gages have demonstrated their products. The specification for the gaging system has been completed. For additional informtion, contact G. Conlon, ARRCOM, (309) 794-5611.

Project 7391. Bearing Diagnostic and Reclamation Techniques. Current helicopter overhaul procedures require bearing replacement rather than repair/overhaul. With proper diagnostic and reclamation procedures, approximately 35 percent of the defective bearings could be restored. This project will develop the technology for identifying defective bearings and the repair/restoration of rejected bearings. The integrated diagnostic and reclamation technique is an advanced technique that is used by private industry. The bearing inventory has been reviewed and inspected. Current and proposed approaches to bearing refurbishment have been analyzed and bearing inspection procedures have been reviewed. For additional information, contact M. Asaad, AVRADCOM, (314) 263-3243.

Project 7412. Infrared Detector for Laser Warning Receiver. Supply of gallium arsenide etalons for use as infrared detectors is limited. Methods for diffusing the detector junction, for surface passivation, for bonding the interdigitated etalon to the interdigitated detector are largely hand methods. This project will develop alternate sources of GA-AS material and automate methods for controlling junction diffusion, for passivation, and for bonding leads to the detector array. For additional information, contact G. Gorline, AVRADCOM, (314) 263-1625.

Project 1071. Hybrid Integrated CAD and Manufacturing (HICADAM). Hybrid circuit design and manufacture is labor intensive. The CAD data base has not been extended to manufacturing process control. This project will analyze functional flow and manufacturing process controls and modify the design data base to make it capable of defining functions, input, output, controls, and interfaces. It will also use ICAM methodology to develop system architecture. For additional information, contact G. Little, MICOM, (205) 876-3848.

Project 1051. Replacement of Asbestos in Rocket Motor Insulations. Present asbestos containing insulators cannot be manufactured after 1981 due to its being identified as a carcinogen. Thus, the government has lost the capability of using insulating materials that have proven to be an excellent thermal barrier. Filler materials other than asbestos are available. Fiberglass and silica have been used in specialized applications and wollastonite looks promising. Materials specifications and motor test verification must be done before a substitute material can be used. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 7351. Composite Shafting for Turbine Engines. Current material capabilities associated with high speed gas turbine engine shafting require excess bearings and careful design regarding shaft dynamics. Recent developments in fabricating metal matrix composite shafting offer increased stiffness and critical speeds by 30-40 percent and can reduce the diameter. For additional information, contact J. Gomez, AVRADCOM, (314) 263-3977.

Project 8017. Pollution Abatement Program. More stringent environmental requirements are being established for air and waste water discharge. New nonpolluting manufacturing processes will be evaluated as substitutes for present air and water polluting processes in the areas of plating, machining, and rubber compounding. The noncyanide copper plating bath was chemically balanced and steel panels were successfully coated. This copper coating met all requirements of copper plating. Additional chemicals for both noncyanide cadmium and copper plating baths have been procured for scaleup to production plating. Appropriate anodes and zirconium racks have been ordered. Techniques for leeching cyanide chemicals from liners were planned. For additional information, contact F. Testroet, ARRCOM, (309) 794-5039.

Project 7928. Robotized Benching Operations (CAM). Benching operations on breechblocks and rings are unsafe and time consuming. This project will develop industrial robots to perform these operations. A feasibility study has been initiated. A sample component was sent to a manufacturer of robots to begin testing on the breeching bushing. To date the testing has yielded negative results—however, manufacturer representatives are optimistic. For additional information, contact V. Montuori, ARRCOM, (309) 794-5507.

Project 7943. Analysis for Modernization of Industrial Operations. Rock Island Arsenal needs effective investment policies for production equipment and facilities. The current project will establish the necessary data base, engineering studies, preliminary designs, and economic analyses from which an effective investment program can be carried out. Building layout selection was completed and project development brochure and related documentation for construction were prepared. Case and Co., Inc. performed a machine replacement analysis, defining equipment replacements. Integration of equipment layouts and utilities requirements is being prepared as part of a facilities master plan. For additional information, contact T. Quinlan, ARRCOM, (309) 794-5804.

Project 7948. Establish Cutting Fluid Control System. The lack of a controlled program for the use of cutting fluids results in high machining costs and stocking of many fluids. This project will establish a program to control shop floor testing and define methods to control use of cutting fluids during manufacturing operations. Data was gathered to document the current use of cutting fluids at Rock Island Arsenal. Five parts were selected as typical items produced at RIA for detailed analysis. For additional information, contact R. Johnson, ARRCOM, (309) 794-5424.

Project 7949. Application of Group Technology Manufacturing (CAM). Present planning, scheduling, and manufacture of weapon assemblies and components are by separate lots and parts which require multiple machining operations, setups, and changes of tooling and which cause loss of time and money. This project will apply group technology to classify, code, and manufacture weapon assemblies and components as families of parts. Parts will be matched by contour and size for simultaneous machining and subgroup for more efficient machining and assembly. The MICLASS classification and coding and supporting group technology software has been implemented. A total of 4772 parts have been coded. For additional information, contact J. Wilkins, ARRCOM, (309) 794-5897.

Project 7985. Small Arms Weapons New Process Production Technology. Gun barrel manufacturing procedures reflect antiquated technology and rely on mass removal of material by conventional machining methods. Current equipment represents 1940-50 technology. New materials compound the problem. This project will reduce to practice new techniques for .50 in. to 40 mm barrels by establishing the technology and process equipment required to bridge the gap between capabilities and requirements. The rifling was cold rotary forged and then returned for finish machining. The SOWS and RFP are complete to Maremont for evaluation of barrel manufacturing processes. For additional information, contact R. Pizzola, ARRCOM, (309) 794-6450.

Project 7284. Superplastic Forming/Diffusion Bonding of Titanium. Current engine compartment structures employ either steel or titanium to meet the high temperature requirements. As sheet metal structural components, these alloys are expensive to fabricate and assemble. This project will develop a manufacturing process that uses the superplastic forming and diffusion bonding (SPF/DB) properties of titanium to produce engine compartment structures and airframe parts. Two superplastically formed firewalls are being chemically milled in preparation for the qualification test. Two more firewalls were formed during this period and are being sent to the subcontractor for machining. For additional information, contact A. Ayvazian, AVRADCOM, (314) 263-3234.

Project 7315. Low Cost Manufacture of Poise Gimbal. The present approach to fabrication of the several gimbals and base plate is casting and machining magnesium. Magnesium gimbals are expensive and have a rather low stiffness. This project will consider new materials (graphite-epoxy or Kevlar-epoxy) that offer the probability of substantially higher stiffness and lower production cost. Material samples of Graphtek were fabricated and tested. Work was initiated on confirmatory and thermal test samples. The project scope was expanded to address the elevation gimbal also. For additional information, contact A. Kleider, AVRAD—COM, (314) 263-4776.

Project 7036. Isothermal Roll Forging of Compressor Blades. Technology for fabricating advanced engine materials into compressor blade configurations is either unavailable or excessive in cost. Isothermal roll forging is a unique fabrication process capable of producing shapes free from surface contamination with surface finishes equal to cold forging at reduced costs. The blades were shot-peended and fatigue tested by AVCO. Initial fatigue data indicates these blades meet or exceed AVCO specifications. For additional information, contact R. Gagne, AVRADCOM, (314) 263-3270.

Project 7052. Ultrasonically Assited Nose Cap Forming. Nose caps used on leading edges of rotor blades currently are being hot formed—a technique which requires long processing times, costly tooling, and expensive chemical etching. This project will develop an ultrasonically assisted cold forming process to fabricate leading edge erosion strips from sheet material. For additional information, contact A. Ayvazian, AVRADCOM, (314) 263-3234.

Project 3050. Epitaxy of III-V Semiconductor Photodetectors. Intrinsic and induced losses limit range of fiber optic transmission. Production means will be needed for a photodetector capable of operation in a spectral region intrinsically less susceptible to such losses. This project will establish production techniques for formation of a quaternary III-V semiconductor photodiode with guard ring, semiautomatic attachment and mounting, and automatic testing of the assembly. For additional information, contact C. Loscoe, CECOM, (201) 544-3276.

Project 5000. Production Hot Forging of Alkali Halide Lenses. Germanium optics used in far infrared systems are expensive. FIR lenses will be fabricated in the laboratory by forging. This forging process must be transferred to a production line operation. This project will develop production techniques to forge these lenses in a production atmosphere by nonprofessional personnel. Honeywell eliminated the use of pressurized helium in hot forging potassium bromide color corrector lenses, enhancing safety. Increased yields allowed replacing the 3x7 batch process with 2x3 bromide lenses replacing zinc selenide lenses. For additional information, contact W. Johnson, ERADCOM (201) 544-6666.

Project 9778. Production of Long Life Light Emitters for Fiber Optics. Wire lenses can be jammed by an electromagnetic pulse/nuclear blast. Fiber optic bundles are immune, but they are hard to attach to light sources and sensors. This project will form light emitting diodes of gallium arsenide phosphide, assemble them into a package, and attach fiber optics by volume production. Laser Diode Labs solved production problems with single stripe injection laser diodes for fiber optic communications. The triple stripe diode consists of three lasing elements mounted in a package equipped with an optical window. For additional information, contact J. Paul, CECOM, (201) 544-1064.

Project 3036. CAD/CAM of Special Electronic Circuits. Semiconductor integrated circuits needed for special communications equipment must be custom designed for each new application. Each integrated circuit requires several mask sets, and a number of integrated circuits are required for each device. Considerable artwork is required. This project will develop computer aided manufacturing techniques that will reduce the cost of and improve the reliability of semiconductor integrated circuits. A contractor will identify costly circuits in the sincgars-V (single channel) radio. Technical management was transferred from the sincgar project manager to the CECOM production engineering support division, which will use CAD/CAM of circuits, components, and assembly. For additional information, contact J. Kelly, CECOM, (201) 544-3276.

Project 8341. Hollow Cylinder Cutoff Machine. Establishing cylinder length is done one of two ways: parted off in a lathe and faced to length or sawed off and then set up in a lathe for facing to final length dimensions. In either case, the operation requires double handling or slow operating procedures. New technology is being developed whereby a set of rotating cutters mills the cylinder to length, producing a face surface to satisfy tube length requirements. Current machining design will not perform this function, but the technology is applicable. For additional information, contact R. DeMeo, ARRCOM (309) 794-5611.

A Wave of the Future

Auto Soldering Machine Use on Rise

Superior performance characteristics of a newly designed automatic wave soldering machine have given this design the lead over its other competitors during a major operational study sponsored by the U.S. Army Missile Command.

Under the direction of the U.S. Army Missile Command, Westinghouse Defense and Electronic Systems Center (Aerospace and Electronic Systems Division) has been investigating improvements and modifications for the MM&T Automatic Wave Soldering Machine Program. In addition, production data have been compared for major phases of the various wave solder machine outputs and operation.

An automatic wave soldering machine produces a ''wave'' of liquid solder; as printed circuit boards are passed over the wave, the plated-through-holes in the boards are soldered. Several Air Force projects (including the ACM-Computer) and the Navy Harpoon project are now utilizing this technology.

Developmental Efforts and Machine Changes

During this first period (October, 1981 through March, 1982), modifications and/or changes were made to the preheater, flux sprayer, solder wave height, board holding fixtures, and conveyor fingers.

To accelerate the chemical activity of the solder flux in cleaning the solder connection, a triple element radiant heating type preheater was added under the conveyor immediately before the solder wave. This resulted in both faster wetting and increased solder flow in the plated-through-holes. Also, after a few months operation, the automatic airless flux sprayer assembly was removed from the machine. This action was taken because the desired low volume of flux spray per PWA required a small nozzle orifice; this small orifice was prone to frequent clogging. Increasing the orifice size eliminated the clogging problem, but it also resulted in excess flux being deposited on the containment surfaces of the sprayer assembly as well as on the machine surfaces around this assembly. Maintenance and frequent downtime were required to remove the excess flux, which proved more of a detriment to the machine's overall operation than the benefits derived from the automatic fluxing system.

Flux is now being applied manually to both the component and solder sides of boards using a hand held spray bottle. An automatic foam fluxer system has been ordered.

Next, board holding fixtures were modified so wave height could be reduced from 1/2 inch to 1/4 inch. This created a very smooth wave surface and reduced the amount of solder dross formation. This smooth wave surface led to further adjustments in the height of the conveyor fingers that carry the board through the wave. Thus, the need for board fixtures was eliminated.

These changes were beneficial in the following ways:

First, flux spraying and preheating the board permits running the board shallower in the solder than previously required.

LLOYD WOODHAM is Project Manager in Computer Aided Design and Computer Aided Manufacturing, System Engineering Directorate of the Army Missile Laboratory, U.S. Army Missile Command. He came to Redstone Arsenal in 1958, starting in the U.S. Army Missile Electronics Laboratory after graduating from Smith—Hughes, Atlanta, Georgia, in Electronics Technology. Among his first assignments was technical support in the assembly of the Army's Redstone tracking station, which was used to determine Sputnik's orbit and to track a number of later Satellites. He later transferred to the Advanced Sensors Directorate and became a Group Leader. He established and managed the first printed wiring board manufacturing facility at Redstone, which grew into the System Engineering Directorate's existing facility. He started work in the Manufacturing Technology Division in 1977.

NOTE: This manufacturing technology project that was conducted by Westinghouse was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Mr. Lloyd Woodham, (205) 876-2521.

Operating Data

Second, running shallower keeps the solder from flowing over the top of the board. This results in time savings and increased productivity (i.e., from not loading the board in the fixture). The loading (30 sec), unloading (15 sec), and cleaning (15 sec) amount to a 1 minute savings per board.

Third, the board is more secure, making it less likely to become dislodged from the finger conveyor.

Fourth, the cost of new and replacement fixtures is saved.

Fifth, using the finger conveyor permits running of all sizes of boards on this machine.

Since flux no longer is sprayed directly on the fingers, the automatic solvent cleaner is not necessary. Therefore, a new automatic finger oiling system was added before the preheater to coat the fingers with a thin film of oil to prevent solder and dross from adhering.

Because of the modification of removing the spray fluxer, several maintenance requirements were eliminated. For example, the operator no longer has to clean the spray fluxer orifice once each shift. A new schedule of maintenance is being prepared and will include maintenance of the automatic foam fluxer.

The pass/fail criteria used in this work is based on the total number of solder defects requiring touchup as a function of the board, classified by area. The pass/fail yield for the MM&T machine was 95.5 percent. The following chart indicates the maximum allowable defects by board based on board area.

Maximum Allowable Defects

Class 1	Maximum Area	50
Class 2	30 sq inches	100
Class 3	60 sq inches	125
	All over 60 sq inches	

Any board with solder defects exceeding the maximum for its classification is considered a failure for yield tracking purposes.

The number of variety of board types wave soldered on the MM&T machine has greatly increased over the last five months. Ninety-five percent of all requirements are now soldered on this machine. Also, the MM&T is being used on two shifts per day. As previously mentioned, the number of different programs utilizing the MM&T machine has increased. Some of these programs include the ACM-Computer, ALQ-131, E3A, F16/APG-66, Harpoon, 616A, HAWK, TWS. All are basically Air Force contracts, with the exception of Harpoon, which is produced for the Navy.

What's Next?

During the next period of this work, the investigation to increase the yield of boards will continue. Also, the parameters necessary to decrease the number of defects per board (particularly insufficient solder) will be reviewed. The automatic foam fluxer will be installed and evaluated, further data on machine production will be gathered, and cost reductions and savings will be determined.

Monthly Summary of Recorded Data on Wave Soldered Boards

Month	Number of Programs		Number Boards Submitted		Number Boards Passed		Yield, %		Total Defects In Thousands		Average # Defects per Board	
	Other	MM&T	Other	MM&T	Other	MM&T	Other	MM&T	Other	MM&T	Other	MM&T
June 81	13	4	1,616	491	1,428	462	88.3	96.0	41.3	20.0	31.9	36.3
July 81	10	4	1,606	742	1,510	717	94.2	96.7	46.6	22.2	29.3	29.1
Aug 81	11	4	1,931	1,319	1,710	1,254	89.0	95.2	68.8	48.0	35.2	35.8
Sept 81	10	3	1,843	299	1,707	293	92.7	95.3	65.1	11.1	35.2	43.5
Oct 81	11	8	1,504	792	1,413	758	93.7	95.8	49.4	24.6	32.5	31.0
Nov 81	7	12	521	1,661	508	1,613	95.7	96.8	16.1	53.5	30.3	32.5
Dec 81	6	7	182	2,519	179	2,414	91.0	96.0	5.9	87.2	35.6	34.3
Jan 82	2	5	3	1,421	1	1,352	25.0	95.2	0.2	38.7	57.0	35.0
Feb 82	1	10	4	1,779	4	1,705	100.0	96.0	0.2	63.8	57.0	35.0
Mar 82	1	8	1	923	1	854	100.0	92.0	0.01	39.5	12.0	43.0
Total/Average			9,211	11,946	8,461	11,422	92%	96%	293.61	408.60	31.88	34.16

Streamlined Production, Cost Savings

Encapsulation Of Electronic Assembly

Aerojet Ordnance recently completed a manufacturing project on encapsulation methods as applied to air delivered mine systems for the U.S. Army Large Caliber Weapon Systems Laboratory. After various methods were investigated, an integrated encapsulation method was selected and tested. Results showed that this process drastically reduced handling and completely eliminated many assembly operations and inspections. While effecting a significant cost savings, the product quality has also been improved. The encapsulation not only gives better support to the electronics than the present method, but it also gives structural support to the entire body assembly.

by

Robert Wade

Project Engineer

U. S. Army Armament Research and Development Command

The MPBMA Contact for this project is Mr. A. Gonsiska, (201)328-4081.

Integral Encapsulation Best

The original goal of this work was to find a superior method of encapsulating the BLU-92/B electronic assembly in an air deliverable mine system. Because the original approach to this work was not feasible with existing hardware design, the closed mold design approach was taken. However, the closed mold design accomplished few of the program goals, so alternative mold designs and procedures were developed and submitted. Among these were open mold, injection mold, integral encapsulation, and closed mold. Several different materials also were investigated. The basis for selection of this new method was due to (1) lower assembly/inspection costs, (2) lower startup (tooling) cost, (3) greatest structural integrity, and (4) lowest production cycle time.

Process Passes With Flying Colors

A feasibility test program developed to verify the validity of this approach consisted of electronic characteristics evaluation before and after assembly operations and after known failure mode environments (thermal shock and impact). Completion of these tests on four units was successful with no parametric or functional failures noted.

Evaluation of electronic characteristics was accomplished with only minor anomalies that could not be associ-

NOTE: This manufacturing technology project that was conducted by Aerojet Ordnance was funded by the U.S. Army Armament R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Robert Wade, (201) 328-4081.

ated with the process being tested. The assemblies used for these tests were production rejects that were reworked for test purposes. No function or data point shifts were noted that were attributable to the encapsulation method. Two areas of interest should be noted: first, the total shift of the oscillators was less than 5 percent and well within specified limits; second, all triplines functioned after impact. All four specimens were subjected to thermal shock per MIL-STD-810C, with electrical characteristics tested before and after. No anomalies were noted.

Impact tests were conducted on the four units with the impact velocity being increased as success was achieved. In the order of firing, the actual measured velocities were 168, 169, 185, and 200 fps. All exceeded the specified requirement of 150 fps. One very high impact distortion was noted that would signify movement of the body assembly. This suggests that at very high velocities and in some attitudes of impact, the body assembly would require additional support.

Functional Assembly Process

Five basic steps (Figure 1) are used in the assembly of this mine system:

(1) The electronic assembly (printed circuit board) is installed and soldered into the housing assembly (unpotted), making the body assembly.
(2) The body subassembly is then placed into the sonic weld fixture and the weld posts are installed.
(3) The tooling pieces are then installed and the printed circuit board area of the body is filled with encapsultant and cured for 10 minutes.
(4) The tooling pieces are then removed and the sensors, associated wiring, and power supply are installed; the battery primer, batteries, and shorting bars are soldered.
(5) The cover and coil is installed and the unit is functionally tested prior to installation into the kill mechanism.

The above assembly process makes the electronics, housings, sensors, and associated wiring integral parts of the structure. In addition to this structural backup, support is provided for all parts and subassemblies.

The assembly process eliminates many inspections now required and product reliability is enhanced by reducing handling and assembly operations. The ability to repair the electronic assembly is maintained until integrated into the body.

Eliminated Steps Reduce Costs

As was previously mentioned, several of the inspection and assembly operations were eliminated by this new method of electronics encapsulation. Based on current production rates and volume, total implementation would produce savings of $173,000. However, these savings would indicate that a production program buy of 50,000 or 100,000 units could effect a multimillion dollar saving.

Therefore, it has been strongly recommended that this integral encapsulation method be instituted as quickly as possible. In addition to cost reductions, this method lends itself well to streamlined production. Additional units will also need to be fabricated for further testing and for familiarizing production personnel.

This MM&T project is being implemented in the GATOR BLU-92/B for incorporation into 1984 production. Also, a 20 month contract to Aerojet Ordnance to build mines for TECOM and U.S. Air Force tests was scheduled for award in December, 1982.

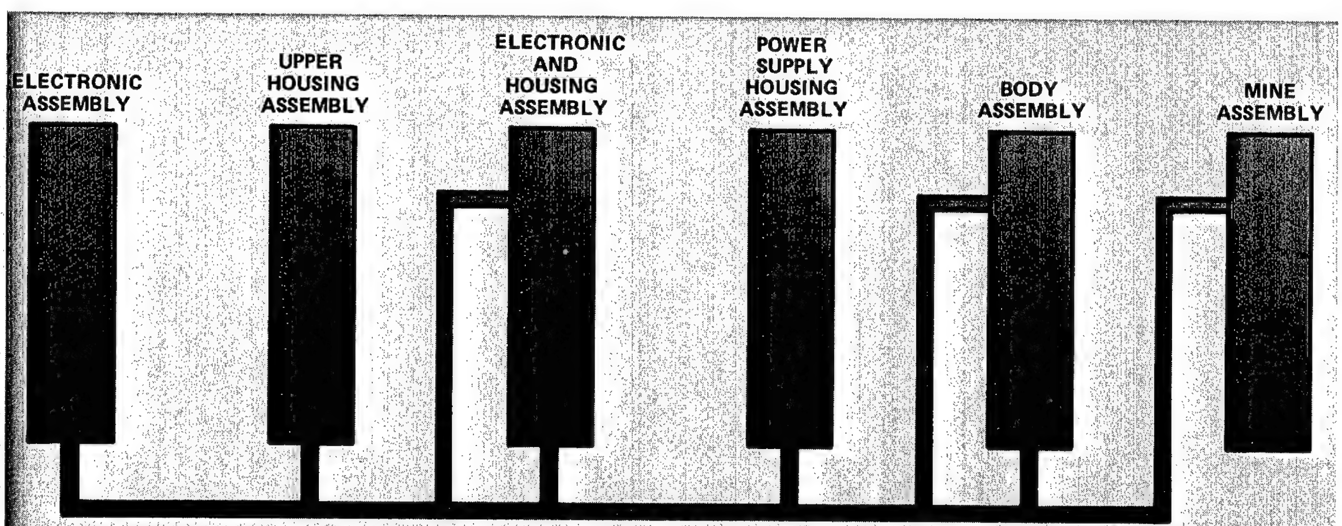


Figure 1

Production Lead Time Cut

Chemical Agent Kit Costs Reduced

Substantial dollar savings plus shortened lead time in the production of the M8 Chemical Agent Alarm system now can be realized if a mobilization should occur, following completion of an MM&T project on their manufacture by the U.S. Army Armament Research and Development Command.

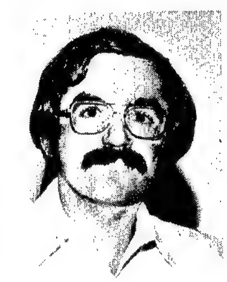
A large number of M229 Refill Kits would be needed to support the M8 Chemical Agent Alarm system in the field should mobilization occur. Therefore, a Manufacturing Methods and Technology program was undertaken by the Chemical Systems Laboratory at Aberdeen Proving Ground. Its purpose—to prepare design criteria for equipment and or a facility capable of producing 40,000 refill kits per month.

Savings per Kit Modest — Net Savings Significant

Equipment capable of meeting the production rate has been selected from commercial sources or designed in-house. Although the machines for production of the filter paddle and capsule were not completed, the technology is available and they could be fabricated with the correct design modifications. The total potential peacetime savings from the ideas generated during the producibility study were $2.68/kit. However, for a production rate of 20,000 M229 Refill Kits, the net savings would be $57,200. And, for a 6 month mobilization scenario in which 40,000 kits would be produced per month (240,000 kits), the cost savings would amount to $686,400.

The M8 Chemical Agent Alarm system consists of a detector, remote alarm, power supply, battery, and the M229 Refill Kit. The detector is a point sampling device used to sample air on a continuous basis. An electrode in an electrolytic cell of the detector reacts when in contact with a specified amount of nerve agent, causing an electrical signal to trigger the remote alarm. This signal warns soldiers that a chemical agent is present so that protective measures can be taken. Power is supplied to both devices via a battery for remote operation or via the power supply for 110/220 volt AC, 50/60/400 cycle operation in fixed installations.

The M229 Refill Kit is required to maintain the operation of the detector. This refill kit consists of 60 filter



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NOTE: This manufacturing technology project that was conducted by the Chemical Systems Laboratory, Aberdeen Proving Ground, was funded by the U.S. Army Armament R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Mr. Richard A. Vigus, (301) 671-4424.

paddles, 30 reservoir jars, and 2 simulant bottles, all packaged in two drawers that are enclosed within an outer cardboard shell. One refill kit will maintain one detector for 30 days of continuous operation. The filter paddle and reservoir jar must be replaced every 12 hours. Twice as many filters as reservoir jars are required because an extra filter is needed to check the operation of the detector after servicing.

At the inception of this project, a requirement existed to provide a capability for producing 40,000 refill kits per month for the M8 Chemical Agent Alarm.

Shelf Life Precludes Stockpiling

The approach was to establish a production rate to meet the requirement for 40,000 kits per month and then to design and/or select all equipment and assembly operations to meet this rate. Consideration was given to stockpiling a sufficient quantity of refill kits to meet mobilization requirements; however, the 2 year shelf life of the refill kit precluded this. After production rates were established for the various components of the kit, the quantities of materials needed to sustain production were determined and provisions were made to receive and store them. The individual operations during production were detailed, and preliminary engineering drawings were prepared for the various operating stations. These operations were combined in a preliminary facility layout and engineering drawings were made for a preliminary facility of the M229 Refill Kit production plant.

During the investigation of the production processes required, several modifications to the refill kit were recommended to allow automated, high speed production of several components. Implementation of many of these changes would only be economical for a high rate of production. Since such quantities are not required for peacetime use, these changes have not been incorporated into the current production of the M229 Refill Kit.

Production Rate Determined

The basis for determining the production rate of the various components was the requirement for 40,000 refill kits per month and a 3-8-7 (three 8 hour shifts, 7 days per week) production plan (70 percent efficiency). The following production rates resulted:

- M229 Refill Kit—1.33 kits/minute
- Filter Paddle—80 filters/minute
- Reservoir Jar—40 jars/minute
- Capsule—40 capsules/minute
- Simulant Bottle—2.66 bottles/minute
- Packaging—1.33 kits/minute.

All equipment and operations were designed or selected to meet the above rates.

The quantity of materials needed and the corresponding storage space were based on maintaining a 2 week supply of all necessary components. Storage space was determined by the production rates listed above and the packaging configurations used by the vendors of the various components. The total storage area required was calculated to be 7200 square feet.

Design Concepts

Batch Processing. The current Bendix supply contract uses batch methods of chemical treatment. A cursory examination of the operations and production rates, which are the bases of the MMT project, indicates that these requirements may also easily be met using batch operations. Batch operations in this case are most easily accomplished using manual feed and unloading methods. Each of the operations of chemical treatment and associated drying require an operator attending a piece of equipment, some motions of which may be automated. Batch operation for the purposes of this design is based upon the treatment of conveniently sized individual sheets of paper stock, since filter disc cutting and assembly equipment is not yet detailed and chemical treatment of a one-filter-wide strip of paper for 5290 filters per hour would not be a feasible batch operation.

Continuous Processing. Production rate and the types of operation involved lend themselves very well to a continuous design for dewaterproofing and impregnation operations. It is also probable that relatively standard processing equipment can be used which, with appropriate modification, can chemically treat a continuous strip or belt of the filter material in an enclosed and controlled manner. The major obstacle to complete continuity of the process is the 15 $\pm$ 1 hour retention time of the impregnated paper at the drying condition, which is specified by DOM #644. This time is significantly in excess of the actual time required to reach constant weight and imposes

a prohibitively great retention time and size upon a dryer through which the stock would move continuously.

Current production contracts do not require the contractor to be bound by the DOM. He does, however, adhere to the extended drying time as a scheduling convenience for his batch operations. Actual experience indicates that only about three hours are required to dry the impregnated paper.

Conclusions/Recommendations

The most critical factor affecting consideration of a process direction at this time is the current DOM requirement of 15 $\pm$ 1 hour retention of impregnated paper at drying conditions. Unless this criteria can be reduced or eliminated, it precludes as a practical matter any recommendation that MMT studies should develop and optimize a totally continuous paper treatment process. It is probable that a totally continuous process could reduce the operating staff to one individual, which at a rate of thirty (30) dollars per hour equates to $0.009 per filter.

Pending a resolution of whether the 15 hour criteria may be substantially reduced or is indeed required, the selection of MMT chemical process development direction lies between totally batch or semicontinuous methods.

Batch process scale-up involves only a moderate (fourfold) increase of current batch practice. The principal innovation beyond Bendix practice that is suggested is semiautomation of handling the paper through the chemical immersion treatments. The MMT study should be concerned primarily with the problems of removing mechanical kinks from the automated operation. Some study must be devoted to optimizing the air input condition of batch drying to meet the minimum DOM retention requirement of fourteen hours.

The MMT study of a semicontinuous process should include the above reference optimization study of batch drying of impregnated paper. The application of equipment for continuous chemical treatment and dewaterproof drying could involve some difficult control problems. With respect to continuous drying of the dewaterproofed paper, the DOM minimum requirement is not an excluding factor. An additional dryer length is required as a cooling section; however, dryer size will not be excessive.

The operational factor most weighting a final decision on batch vis-a-vis semicontinuous MMT study may be the transition from continuous chemical treatment to batch drying of the impregnated paper. There may be difficult problems attendant to cutting a wet, or at best a moist, traveling belt of paper into practical lengths and manually transferring the cut sections to support screens with subsequent placement in a dryer. This should be evaluated as soon as possible in the paper laboratory.

A completely batch process will require two operations, one each for dewaterproofing and impregnation operations.

With prudent design and scheduling it is probable that semicontinuous operations will require only a single operator or fractionally more. This operator would prepare the treatment solutions, handle the transition to batch drying, and monitor the preceding continuous operation.

The potential labor cost advantage of a semicontinuous or continuous chemical treatment process is minimized if total procurement time is short. It is entirely possible that this labor difference will be a minimal consideration in context with the entire production staff and therefore not an appropriate measure for decision.

Batch Concept Most Feasible

It is recommended that batch processing be adopted as the basis for MMT studies. This recommendation is based upon the following factors:

(1) There is no current clear cut evidence that relief will be obtained from the fixed drying period for impregnated material.

(2) In view of the fragile nature of the filter material when wet, it is probable that equipment of considerable sophistication will be required to effect a continuous transfer, without damage, from feed rolls to dewaterproofing, thence to dewaterproof drying, and finally to impregnation treatment. Such equipment would appear to require significant capital and maintenance costs, while production requirements remain small.

Batch Facility Flowsheet

The batch operation flowsheet is conceived as including the following combinations of material movement (see figures 1 through 5):

- Cutting of Type 5 paper stock rolls into conveniently sized sheets
- Preparation of chemical treatment solutions
- Dewaterproof treatment of sheets including manual feed to DWP operation, semiautomated chemical treatment, manual unloading, manual loading of DWP dryer
- Manual unloading of DWP dryer
- Impregnation of DWP sheets, including manual feed to IMP operation, semiautomated chemical treatment, manual unloading, manual loading of IMP dryer
- Manual unloading of IMP dryer to interim storage pending QA release.

Operations and Facility Layout

Production of the M229 Refill Kit requires many individual operations. Some of these, such as component loading and final packaging, lend themselves readily to automation; others, such as insertion of the safety clip into

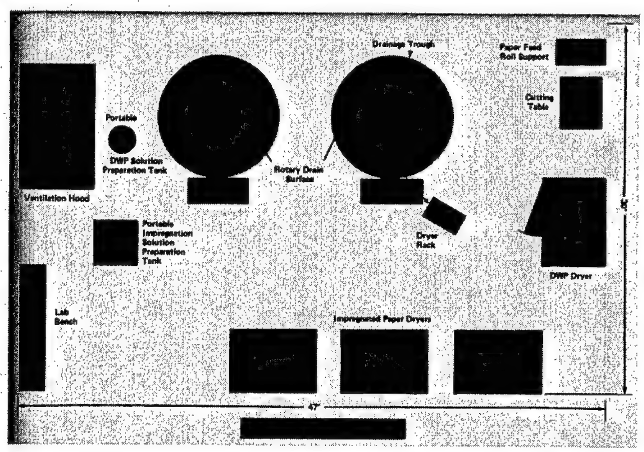

Figure 1

the cutter, do not. An attempt was made to automate as many operations as possible. A detailed layout of the manual or semiautomated operation was prepared for those operations which could not be automated due to the lack of available equipment or technology. Figures 6 through 9 show layouts of the stations for, respectively, simulant bottle fill and assembly, reservoir bottle assembly, O-ring placement, and cap assembly. Some of the various operations involved were a capsule assembly machine, filling and assembly of reservoir and simulant bottles, and drawer and kit assembly. In the filling and assembly of reservoir bottles, for example, the empty reservoir jars are set in an unscrambler which feeds the jars onto a conveyor. The conveyor moves four jars at a time to the filling heads. After the jars are filled, they are split into two streams and taken by conveyor to the cap torquers. A cap is manually placed on the jar and then torqued automatically. The capped jar is fed to a tester for leak checking to ensure a good cap fit.

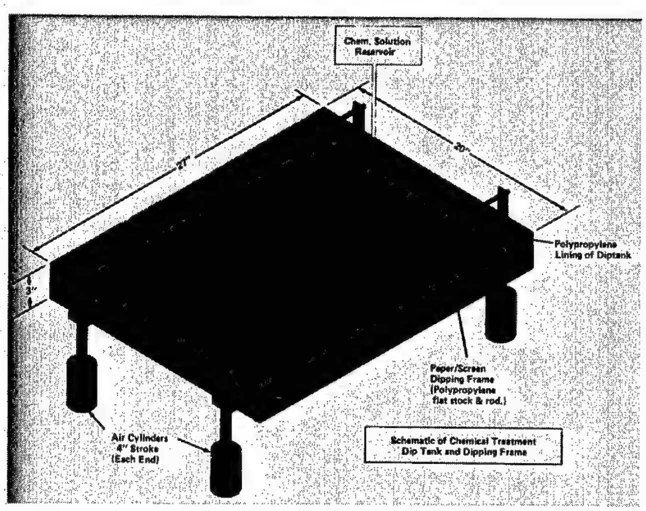

Figure 2

Equipment Requirements

Equipment requirements, including selected automated commercial equipment, involved such items as a heat shrink gun, a sleeve packer, a drawer former, and a drop packer for reservoir jars. The drawer former requirement was filled with a commercial piece of equipment which will form the drawers at a rate of 12 to 35/minute. This rate is slightly faster than needed, but this can be remedied easily by intermittent, rather than continuous, operation. The machine requires a 220 volt 3-phase power source.

Suggestions for Improved Production

During the course of this work, several changes were suggested to improve production of the M229 Refill Kit. For example, if automated equipment is used to package the filter at high production rates, both the inner and outer packages of the filter need to be changed. The new packages will be longer and thinner than the existing ones to fit the packaging machines. Also, the automatic process produces sealed ends and backs and packages the filters at the required rate of 80/minute.

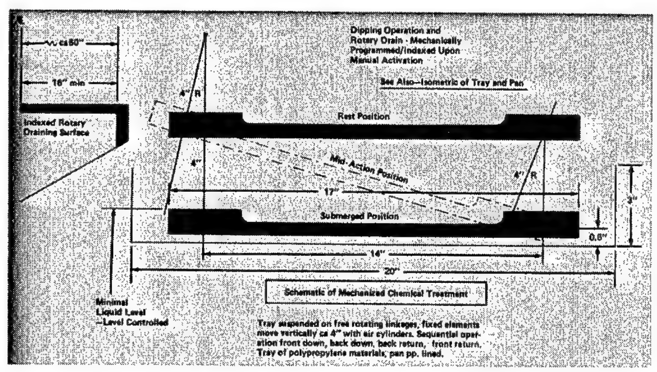

Figure 3

The cost increase in materials for the proposed packages will be offset by the reduction in labor cost. The cost for packaging the filters by hand is approximately \$3.60/kit, as opposed to only \$0.25/kit for the automated operation, resulting in a \$3.35/kit savings. The materials cost for the inner and outer bags will increase \$1.37/kit, resulting in a net savings of \$1.98/kit, which is economically feasible.

In addition, if the proposed changes to filter paddle packages are used, the dimensions of the drawer, sleeve, fiberboard box, dividers, and shipping container will also have to be changed, as well as the packaging scheme of the drawer. These changes also necessitate the use of a larger box, thus increasing material cost. However, this increase will be only \$0.68/kit and will be offset by the \$1.98/kit savings from filter packaging. The overall net savings is \$1.30/kit, making the packaging modifications economically feasible.

Other modifications include eliminating several parts

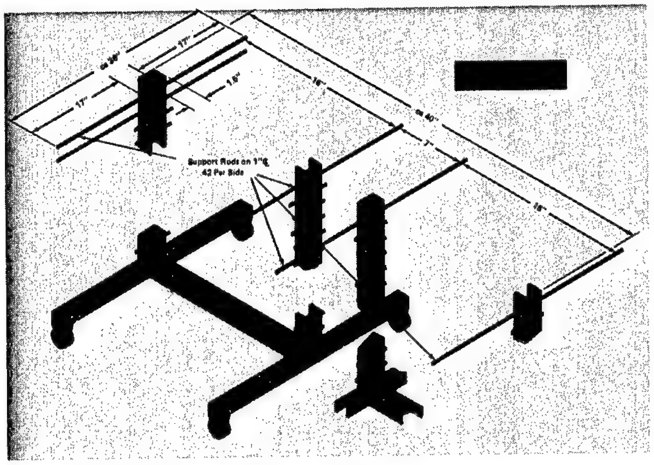

Figure 4

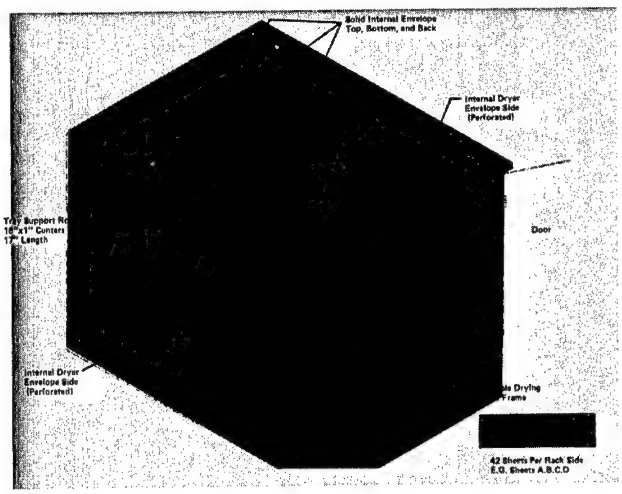

Figure 5

such as handles and modifying others:

- Modification of the fiberboard box to open from the side with a strap on top

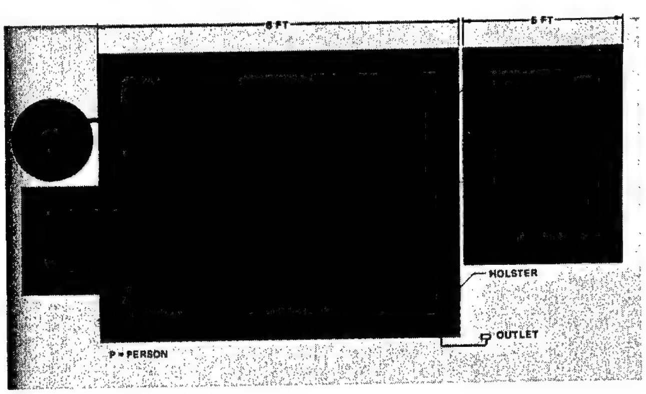

Figure 6

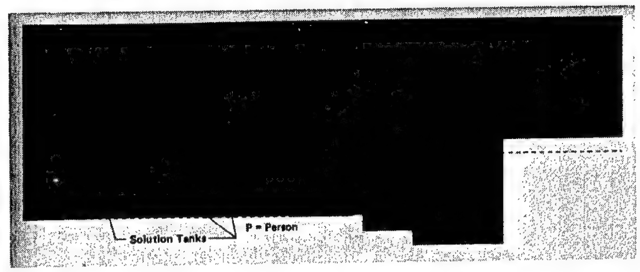

Figure 7

- Modification of the drawers to include finger holes for handling.

Due to the effort put forth by the staff at Aberdeen Proving Ground in this project, the Armed Forces will be supplied with the necessary refill kits for their chemical agent alarm systems should the need ever arise. And it should be noted that a significant savings in cost also resulted.

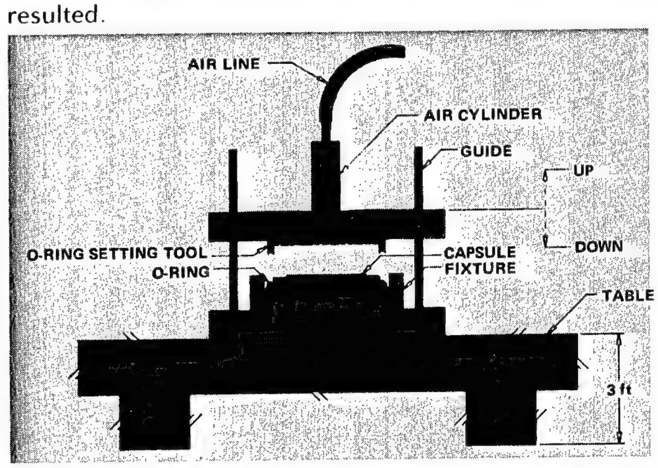

Figure 8

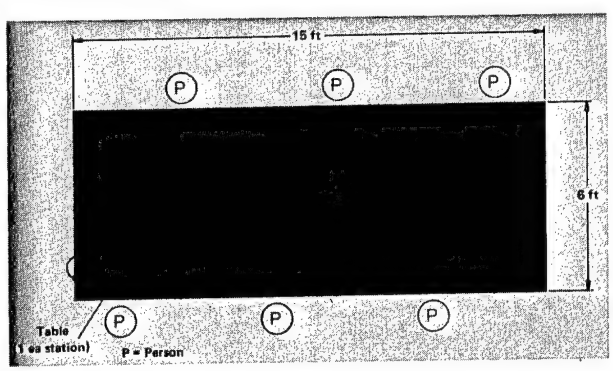

Figure 9

Cost Reduction, Property Enhancement

Mortar Bodies, Projectile Preforms Sqeeze Cast

Considerable long term energy savings (and dollar savings) are expected with the successful application of squeeze casting techniques to the production of the U.S. Army's 81 mm M374 mortar bodies and 155 mm M483 projectile body preforms, following completion of a manufacturing technology project for the U.S. Army Armament Research and Development Command.

Squeeze casting of these components was recently accomplished at the Illinois Institute of Technology Research Institute (IITRI). Squeeze casting is a hybrid (or marriage) of conventional casting and forging techniques which involves a one step conversion of molten metal into near net shape components or preforms. Also termed "liquid metal forging" (originally borrowed from the Soviets), this process involves pouring molten metal into metallic dies in a hydraulic press and solidifying the metal under high hydrostatic pressure through the application of direct press tonnage.* (See Figure 1)

In this program, both pearlitic malleable iron and ductile iron were evaluated for squeeze casting of the mortar body. Ductile iron proved to lend itself better to squeeze casting and was selected for optimization studies. The preform for the 155 mm M483 body was squeeze cast from 1340 steel. The possible enhancement of properties resulting from squeeze casting these materials and the potential for cost reduction were two areas of major interest.

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Photograph Unavailable

*See ManTech Journal, Vol. 3, No. 3, pp. 32-34, "Squeeze Cast Missile Domes Feasible".

MPBMA Contact: Mr. Y. Wong, (201)328-4084

NOTE: This manufacturing technology project that was conducted by IIT Research Institute was funded by the U.S. Army Armament R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Mr. Duane O. Gustad, (201) 328-2522.

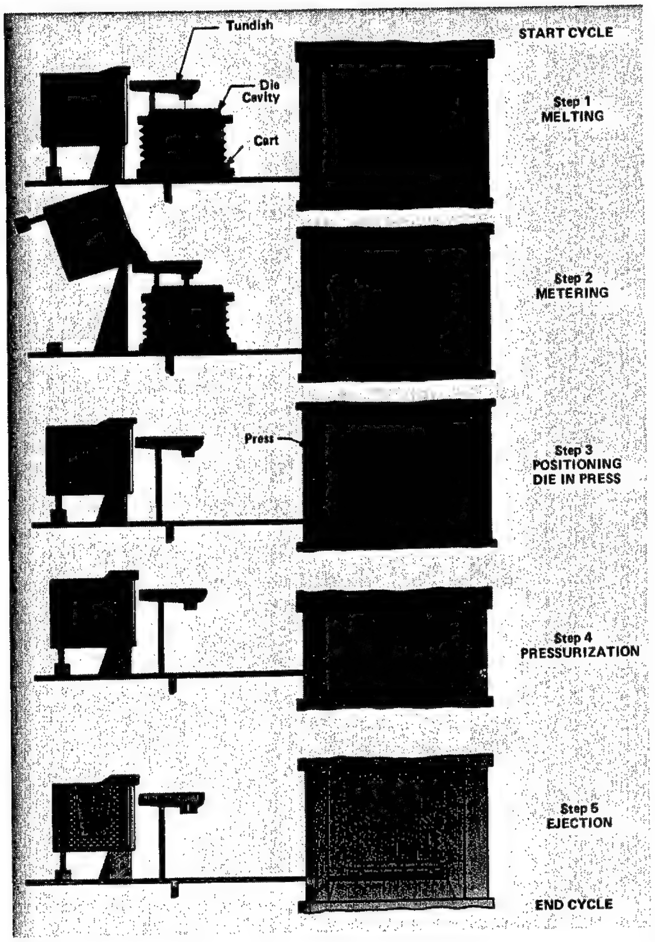

Figure 1

H13 Steel Used in Dies

Phase I of this work began with the die design and fabrication. A machining allowance of 2.5 mm (0.100 inch) diameter was provided for the outside surfaces of both castings. Thermal contraction corrections were also incorporated so that the final dimensions for the squeeze castings could be obtained. Major die components were fabricated from H13 steel, while less critical components were made from hot rolled steel.

Squeeze casting experiments were conducted using a 1000 ton hydraulic press for the projectile preform and a 250 ton hydraulic press for the mortar body. A 70 kg (150 lb) high frequency induction melting furnace was used to melt the SAE 1340 steel for the preform, while a 4½ kg (10 lb) induction furnace mounted on the 250 ton press served as the melting system for the mortar body. Standard procedures were used in both cases for melt composition control and time-temperature relationships during melting.

Experiments Define Parameters

Following an initial series of mortar body squeeze castings in aluminum, several castings were made using both nodular iron and malleable iron to evaluate their relative performance during squeeze casting. On the basis of these experiments, nodular iron was found to be better suited to squeeze casting. The mortar body dies were then redesigned and rebuilt to result in a thinner casting wall closer to near net shape. Final optimization was then undertaken. The principal process parameters included casting temperature, pressure level, delay time between pouring, and die closure. (See Figure 2).

The as cast microstructure of the nodular iron squeeze casting showed massive platelets of carbide formed due to the rapid rate of heat abstraction from the casting to the metallic die, with insufficient nodulization. The as cast structure thus was extremely hard and brittle. After aneal-

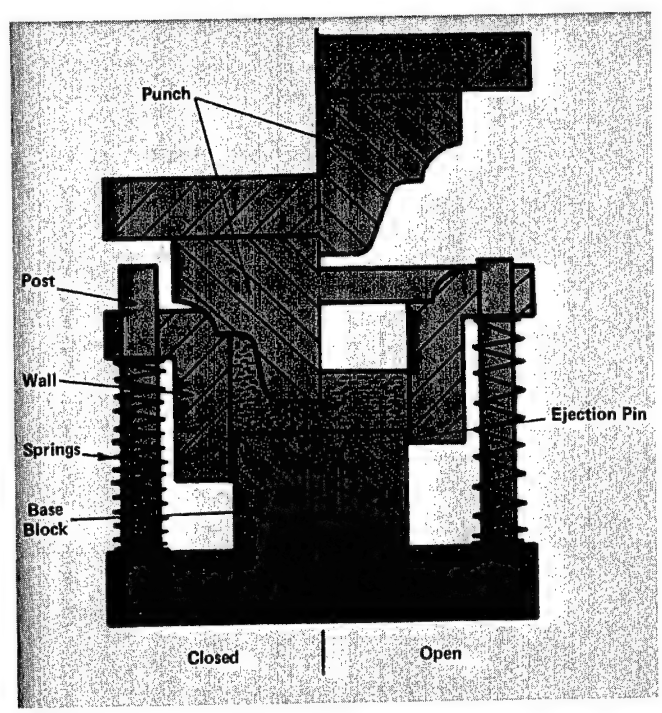

Figure 2

ing, the microstructure showed a large number of graphite nodules in a matrix of ferrite grains, with no carbide phase present. Thus, the microstructure and the resulting properties may be readily controlled to within specifications by adjusting the annealing cycle after squeeze casting.

Geometry Related Variables Most Important

Following mortar body die modification (to produce castings with a 2.5 mm or 0.100 in. OD machining allowance), a series of 22 squeeze castings was made and sample castings were examined by sectioning—destructive testing as well as by radiography and magnetic particle inspection (NDT). The results indicated that all castings produced under the optimum conditions of poured weight were radiographically sound. Magnetic particle inspection revealed surface flaws, but these were found by dye penetrant testing to be surface depressions, not cracks.

Geometry related variables were found to be most important in influencing the product quality (porosity level)—particularly, the base thickness of the casting. When the base is too thick, hot spots that developed in the base cause shrinkage pores in that region. (See Figure 3). When the base is too thin, it freezes prematurely and subsequently does not transmit the punch load to the walls of the casting. The pore site is thus moved to the wall region. Between these two extremes of base thickness (18 mm minimum to 33 mm maximum), pore free castings can be produced with adequate latitude for errors in the poured melt weight.

Pilot Run Produces Problems

The second phase of this program involved the production of 50 deliverable mortar body squeeze castings, their testing and evaluation, and a cost analysis. However, during the course of this production run, the punch was observed to lose its original shape near the tip, resulting from prolonged exposure to an environment which combined high pressure with high temperature.

The pressure level originally applied was successful in eliminating porosity. It was felt that decreasing the duration of pressure by 5 seconds would not affect the quality of the casting, but would greatly alleviate the distortion of the punch, which was becoming a matter of some concern.

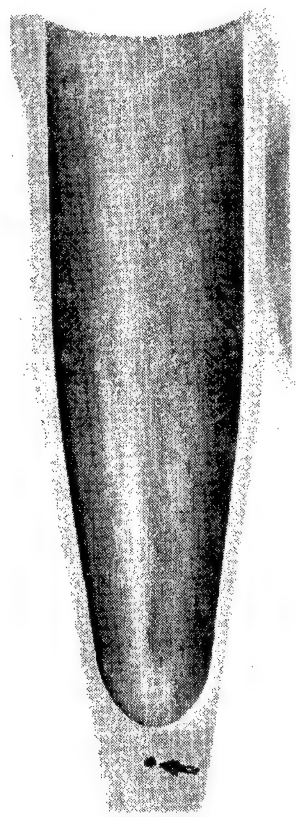

Figure 3

Pressure Reduction Success Limited

The reduction in pressure duration was successful in arresting the progressive deformation of the punch. However, a 100 percent radiographic check showed that an overwhelming majority of these castings had shrinkage porosity in the base region. Therefore, the duration of pressure had to be increased to an intermediate level to overcome this problem. The casting temperature was also raised slightly to improve the surface finish and eliminate occasional cold laps observed at the previous temperature range. (See Figures 4 and 5).

Overcoming the problem of punch deformation in production will require the use of a punch material with better high temperature strength than H13. An alloy of tungsten or molybdenum may be required to provide the necessary refractory characteristics. Cooling of the overheated tip of the punch may be required to maintain the operating tooling temperatures within the desired range.

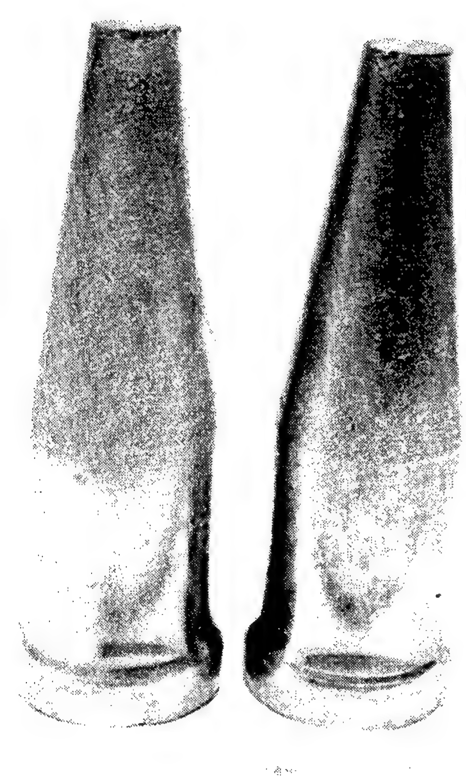

Figure 4

Abbreviated Heat Treating Doesn't Work

In accordance with contract requirements, 50 mortar body squeeze castings were then selected for heat treatment. This selection was based on surface appearance, radiographic sampling, and dimensional conformance. (See Figure 6).

In heat treating the relatively brittle mortar body squeeze castings, the abbreviated cycle adopted by a commercial vendor produced high thermal stresses in the castings leading to cracks in the junction between the thin wall and the thicker base. Twenty-three squeeze castings were damaged in this manner.

The remaining 27 castings were retrieved and heat treated by IITRI following standard procedures. All were successfully heat treated, with tensile results conforming to target specifications.

Equipment Cost High

The equipment for melting, melt transfer, squeeze casting, and parts handling should be consistent with ARRADCOM's production requirement of 200,000 M374 mortar body squeeze castings per month, or a 288 parts/hr rate of production (slightly in excess of 200,000 parts/month). The principal equipment requirements and costs would include:

- Melting equipment (cumulatively capable of melting nodular iron in quantities of 27.65 tons/day, estimated at $100,000)
- Melt transfer equipment (needs development—to transfer molten nodular iron into the die cavity in quantities of 3.25 ± 0.23 kg unless a charge compensator can be designed into the die; no cost information presently available)

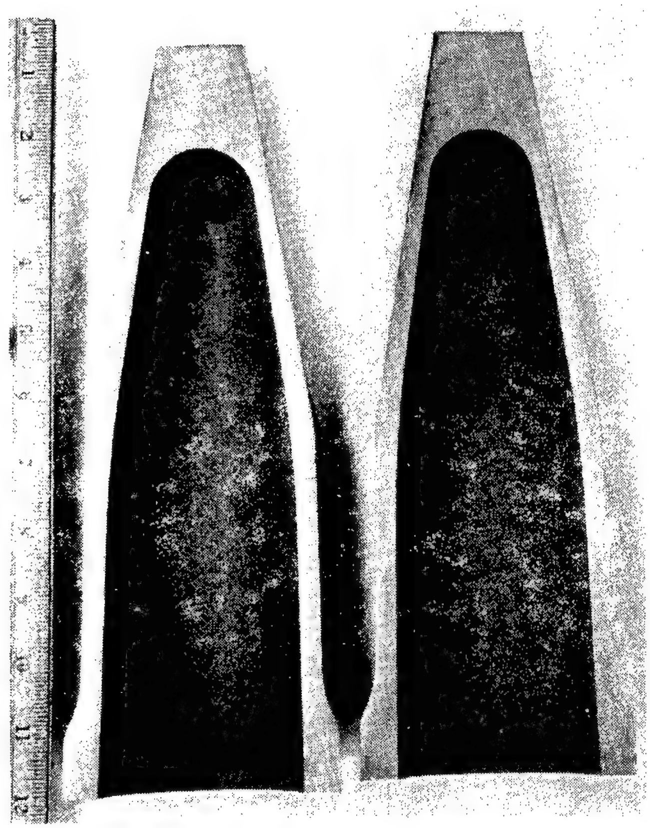

Figure 5

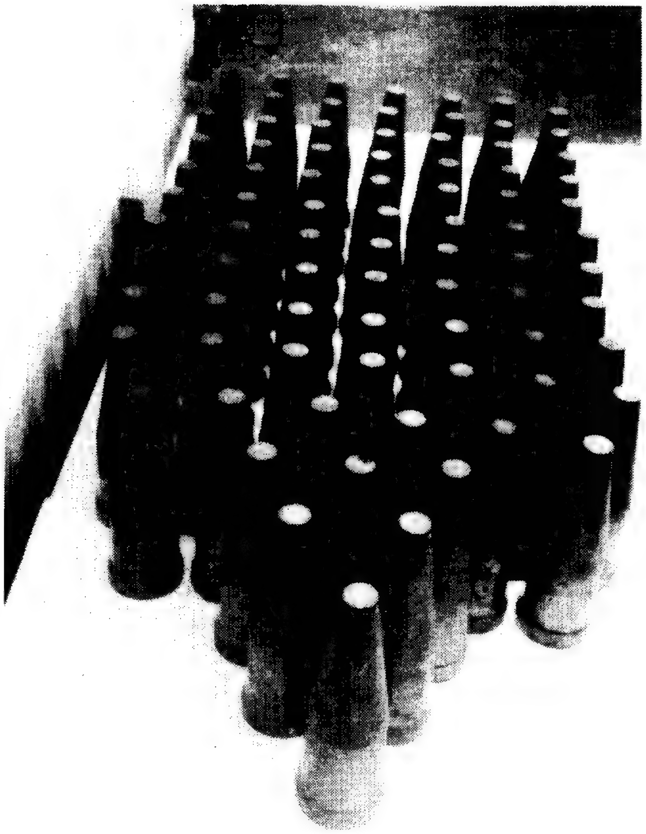

Figure 6

- Hydraulic press (150 tons, single action, 1.1 m daylight between bolsters, 0.6 m stroke, 0.6 x 0.6 m bed area, and up to 0.25 m/s speed; press costs estimated to be $200,000 per unit).

In addition, the dies for squeeze casting have to be designed to withstand internal pressures of about 210 MPa (30 ksi) at surface temperatures of nearly 1260 C. The bulk temperatures in the punch and die would be in the range of 260-370 C, with initial preheat supplied by gas burners (or other similar means) and with temperature control within these limits achieved by circulating cooling water through channels in the punch and die. As previously mentioned, H13 steel is recommended for the die and support members, but a refractory alloy based on tungsten or molybdenum would be required for the punch to prevent bulk deformation of the tip of the punch in the high pressure-high temperature environment. The dies may be designed as single stage dies or as transfer dies using a carousel type of arrangement.

High vs Low Productivity

Squeeze casting may be used in either a high productivity or low productivity environment. In the case of high productivity, squeeze casting will require three presses, each operating a four station die and producing 96 parts/hr for a total of 288 parts/hr. Thirteen people would be required to maintain three press lines at these rates of production.

In a low productivity case, squeeze casting would be done using single stage dies. The use of single stage dies will require 12 presses, each producing 24 parts/hr, and 31 people to operate.

For both cases considered, the as cast mortar body can be produced for about $4-5.50, depending on the type of operation, for production quantities of 200,000 per month. Costs for heat treatment, machining, and nosing would be extra. The costs are based on realistic estimates of raw material cost, wages, cycle time, and tooling costs. Depreciation of plant equipment other than dies (expendable) has not been considered directly, but rather as a factor in arriving at the applicable overhead rates in each case.

Squeeze Casting Saves Energy

Squeeze casting is an energy efficient process in terms of the energy content of the squeeze cast product. Other processes, such as cold forging, may use less energy during the actual processing, but they make use of starting materials (wrought preforms) that already have considerable energy expended in their preparation. From the standpoint of total energy consumed, cast products usually compare favorably with wrought ones.

In comparison with conventional casting processes, such as sand casting, squeeze casting uses more energy on a per pound basis because of the pressworking requirements. Sand casting, however, provides a metal yield of no better than 50 percent; this results in a considerable energy expenditure when one considers the repeated remelting of the trimmed excess of the casting. A near net shape process like squeeze casting is thus more energy efficient in terms of the total energy content of the finished product.

The technical feasibility of squeeze casting munitions shapes has been established; however, there are still several areas such as melt transfer, melt metering, and improved punch tooling material that need additional development before the squeeze casting process can be implemented into a high volume production application.

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Fluoroscopy Offers Potential

New Radiographic Inspection System

Practical radiographic inspection using non-film systems now is a real possibility, following recent improvements in fluoroscopic screens, electro-optical devices, and image processing technology. These new developments have substantially reduced the gap in X-ray image quality between film and direct viewing systems.

A new prototype non-film radiographic inspection system that has been developed by Boeing Aerospace for the U.S. Army Missile Command is capable of performing rapid assembly configuration verification of large complex assemblies. The system also includes capabilities for:

- Real time X-ray radiography
- Digital image enhancement
- Remote part positioning and manipulation
- Computer aided inspection.

A major benefit of this system is the dramatic cost savings in addition to faster and more thorough inspection.

Film Processing Prohibitive

Products such as missile components must pass an X-ray inspection prior to release from the manufacturer. This is to assure that all internal parts are assembled and functioning correctly. Without verification by radiographic inspection, a defective missile could be deployed, with potentially catastrophic results.

Radiographic examination of critical low rate production components and assemblies traditionally has made use of film processing methodology. However, this is prohibitive for high rate production due to the high labor and film costs and excessive flow time. Fluroscopy offers the best potential to replace conventional film radiography. Applications of real time systems have been limited because the X-ray image is generally of lower quality than film. Low sensitivity has been a major drawback in applications requiring detection of very small flaws, but when examina-

NOTE: This manufacturing technology project that was conducted by Boeing Aerospace was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bobby Park, (205) 876-2147.

tion requirements are primarily related to hardware configuration, spatial resolution is of lesser importance.

The purpose of this project was to develop and demonstrate a prototype nonfilm radiographic method for verifying the configuration of large, complex parts. The ROLAND missile final assembly inspection was chosen as the target application for this project, however the techniques developed could be used for inspecting the internal configuration of any complex missile or part.

$1.1 Million Savings

In this system (Figure 1), the X-rays which pass through the test part fall on a fluoroscopic screen instead of a photosensitive film. The fluoroscopic screen converts the X-rays to visible light, and a camera transmits the image to a remote monitor. Remote control of part motion allows the operator to inspect the part at every angle and position. The real time image may be digitized so that image enhancement techniques can be performed upon it. The digitized image may be saved on a magnetic tape or disc associated with a computer system. Automatic control of parts positioning and image processing allows a computer aided inspection scheme to be used.

It is estimated that a cost reduction of 8:1 and flow time reduction of 5:1 could be achieved through the implementation of non-film methods. For the ROLAND missile this would result in a savings of over $1.1 million based on a production of 10,000 units.

Three Areas Covered

The scope of this project covered the evaluation of three areas: real time X-ray, image processing, and computer aided inspection. The real time X-ray system includes a

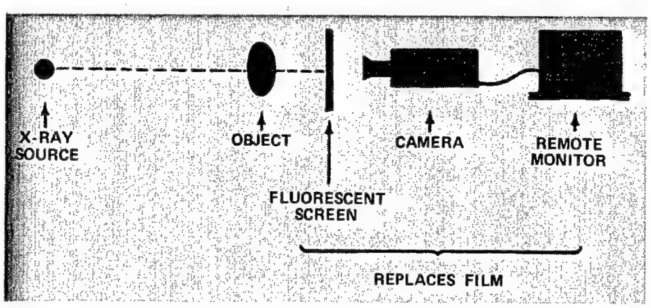

Figure 1

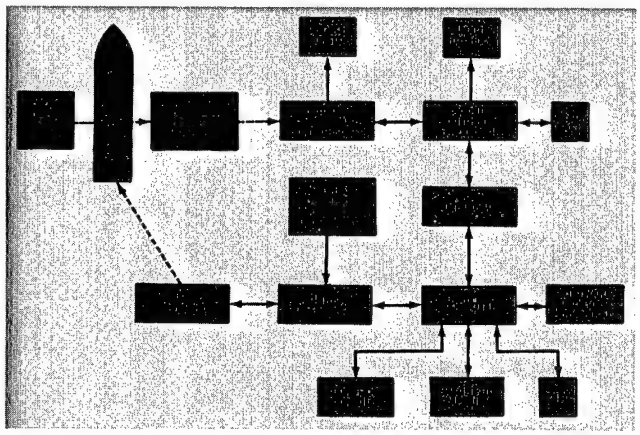

Figure 2

fluoroscopic image intensifier tube, an antimony trisulfide vidicon camera, a TV monitor, and a remotely controlled part manipulation table. Digital image processing was executed under control of a computer system and was performed on digitized images. The computer aided inspection system controls routine procedures such as part positioning, image processing sequences, and storage and retrieval of records and images. Computerized decision making was not investigated and did not fall within the scope of this project.

After the real time imaging system was assembled, part manipulation and image processing systems were added. A prototype computer aided evaluating inspection system was then developed. Optimization of the real time images of image processing techniques and determination of the best testing procedure for the computer aided inspection were accomplished. It was then possible to perform a cost/benefit analysis for these systems.

Specific Equipment

Figure 2 is a block diagram of the overall system. Individual items include an X-Ray Generator, An X-Ray to Visible Light Convertor and Intensifier, a Video Camera, a Video Monitor, an Image Processor, a Computer System, a Parts Control, and various interfaces.

The real time X-ray mechanical equipment was assembled to permit a complete examination of the ROLAND

missile. A part manipulation table supports the missile at each end and was constructed with three degrees of freedom: longitudinal, transverse, and rotational. The longitudinal and transverse movements permit a full scan of the missile over the total length and width while it is continuously rotated. A remotely controlled lead shield permits selective examination of small areas and reduces scattered X-rays, improving sensitivity. The X-ray tube height can be adjusted to achieve a source to fluorescent screen distance of up to 210 cm. All movements are electrically controlled and can be remotely adjusted.

The prototype system enables the missile to be manipulated, allowing evaluation of all of the defined inspection locations. Motor drive systems were installed to allow automatic positioning of the missile simulating actual production testing operations. Radiography was performed vertically in the prototype system to comply with safety regulations for the particular facility. Modification of the mechanical system will be accomplished during the production implementation to accommodate horizontal radiography.

Radiographic Equipment

The equipment necessary for real time radiography—in addition to a source of X-rays—falls into two categories: (1) the conversion of X-ray light to visible light and (2) the viewing of the converted radiation. Fluorescent screens, which convert X-ray light to visible light, involve X-ray image intensification. As a result of this intensification, the image contrast is significantly reduced, resulting in a lower dynamic range than that of fluorescent screens.

Because direct viewing of a fluorescent screen or image intensifier is not practical due to the geometry, radiation hazard, and low light level, a video camera and remote monitor is a convenient system for viewing the visible image. There are two video tubes commonly used in this application: vidicon and isocon. The vidicon is an inexpensive tube but has low sensitivity and dynamic range; it is also blinded by high light levels. The much more expensive isocon tube has high sensitivity and a wide dynamic range. A Sierra Scientific Corp. Model LSV-1 video camera with an antimony trisulfide vidicon tube was used during this study because of availability and cost. Two image intensifiers were utilized at different times. The camera and intensifier were optically coupled by two KOWA fixed focus lenses.

Image Processor

Two systems met the minimum requirements for an image processor for this work. The Model 70/E (manufactured by Stanford Technology Corporation) was selected from the two because of the following advantages: its input/output transfer rate was four times faster than the other unit; the time for conversion from video to digital with 8 bit resolution was four times faster; processing speeds for additions, subtractions, multiplications, etc., were as much as 17 times faster; and the Model 70/E has hardware histogram generation and hardware min-max pixel intensity calculation as opposed to software generation in the other unit. Further, the software package and documentation also was better for the Model 70/E.

Computer System

The computer selection for this project was based on ability to meet the specific hardware, execution speed, and software requirements to facilitate development and to execute implemented tasks.

Also, the memory management system must manage a large records data base, control mechanical motion, and be capable of executing a large program that manipulates an image in memory. Six systems were examined after preliminary screening. Two of these computers were examined in detail with the Prime 550 chosen for this program.

Advantage of Motion

Real time radiography allows movement of the test part during the radiographic inspection. This is one major advantage that real time X-ray has over film radiography for the inspection of most complex items. Motion of the part, especially rotation, allows the observer to integrate the total picture and build a three dimensional impression, greatly enhancing the ability to detect and identify flaws and perceive their location.

When a part is in motion, small flaws may be easily differentiated from background noise or system imperfections. The ability to view a part in motion provides a rapid means of scanning complex parts at various angles, allowing more reliable identification of any defects. The lower resolution inherent in real time radiography is compensated for by the advantages of motion. Thus, real time X-ray easily permits 100 percent inspection of a part, which is impractical with film techniques for most applications.

Image Processing

Although the real time system described above permits examination of a part while it is in motion, it does not provide the contrast or resolution of film methods. Image quality may be improved considerably through image processing.

Image processing can be accomplished by two basically different approaches—video signal processing and digital image processing. Video signal processing provides a very rapid response to changes in an image, which is tantamount to doing real time image enhancement. However, it is a very limited and inflexible technique. Digital image processing, a more versatile, computer controlled method, was selected for this project. Digital image processing technology has advanced rapidly in recent years because

of the vast amounts of satellite (LANDSAT) data available for land use planning and image processing. The processes applicable to this study were fundamentally of four types: noise reduction, edge enhancement, contrast manipulation and color representation.

Radiographic Records Important

The elimination of X-ray film necessitates using an alternate method of image storage. The requirements for such a method are that (1) the image must be stored for a long time, (2) it must be easy to retrieve, (3) it must retain the original quality of the image, (4) it must be able to be entered back into the imaging system, and (5) it must have a low cost per image. The following types of storage methods were examined: video tape, video disc, microfiche, digital disc, and digital tape. After examining all of these methods, it was felt that image storage on digital tape best met the storage requirements for this work.

Computer Aided Inspection

One of the goals of this project was to demonstrate a prototype computer aided inspection system. In the automated non-film radiographic system, the computer controls parts positioning, records management, and the functions of an inspection plan.

The automated system provides computer control of the manual functions that are labor intensive or sensitive to human error. These primarily fall into the category of data recording and retrieval. Examples of this are inspection plan preparation and dissemination, inspection results recording and retrieval, and radiograph (image) storage and retrieval. A successful system must have certain basic capabilities. Among these are: simple plan preparation and modification procedures, minimum input from the operator (radiographer), and maximum traceability (retrieval of records, re-creation of inspection, etc.).

The automated inspection system software termed CAI (Figure 3), for computer aided inspection, has three basic functions: inspection, planning, and data retrieval.

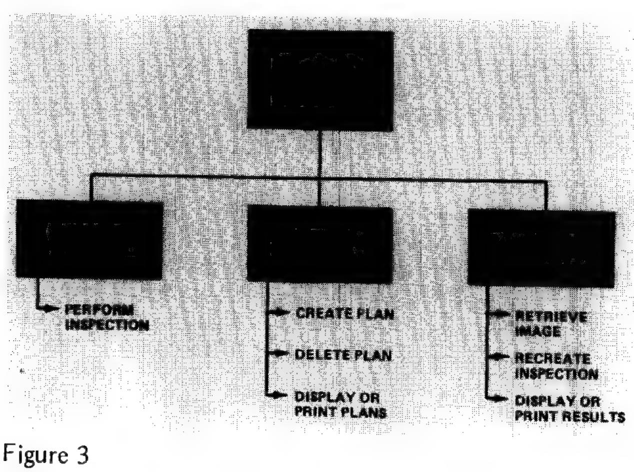

Figure 3

The inspection plans are actually composed of three separate files: first, the plan main records, each containing primarily a list of test names; second, the plan test file, containing records with the basic data for a specific test such as motor and position parameters, special instructions for the inspector and names of image processing functions; and third, image processing command file with each record containing a series of image processing commands. This data base structure allows the planner to create a new plan by merely assembling a list of tests in the order desired. The computer then accesses those tests by name from the various files at the time the inspection is performed. As the inspection is performed, the test results are saved (pass/fail and inspector's comments) along with a copy of the test plan. The last file maintained by the system is the image storage file, a cross reference of magnetic tape names, image names, and unique inspection names.

Inspection. The inspection function of CAI is designed around a data base management system which interacts with an inspector who has no knowledge of image processing. The operator need only enter, at a keyboard, his identification (Stamp No.), the Part No. to be inspected, name of the inspection, and the part's serial number. The computer will access a data base containing the inspection plan for that part. That plan will contain all of the necessary data to run the test: coordinates to position the part, functions and parameters to control the image processor, and instructions for the inspector indicating the key inspection criteria. The inspector then enters a pass/fail decision and any observations for future reference. This then is saved in the historical data file and a copy of the image is recorded on digital magnetic tape (Figure 4).

Planning. The planning functions are, like the inspection functions, designed around a data base management system. These tasks are greatly enhanced by a screen editing capability. Screen utilities are a software package designed to allow interactive data entry. In this case a planner sits at a CRT terminal and modifies existing plans or creates new plans by entering data into specified fields. The data transferred to the data base is controlled by the screen format and the application program (software). The planning package provides the following operations: create new plan records, modify existing plan records, make new records from old, delete plan records, display or print plan or result records, and display or print lists of existing records.

Data Retrieval. For the data to be of value, there must be a means of retrieval of all data and re-creation of the original conditions that allowed the inspector to make a pass or fail decision. To provide these capabilities, it is necessary to not only save the image and results of inspection but also a copy of the inspection plan at the time of inspection (Figure 5). This is necessary because of the possibility that the inspection plan records may be modified or deleted between the time the inspection is per-

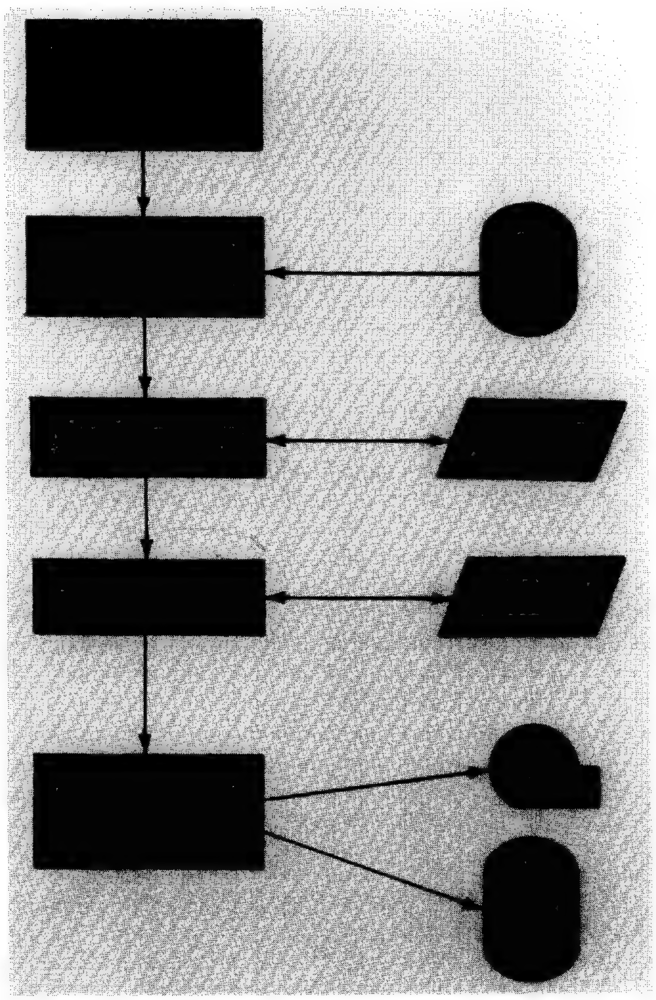

Figure 4

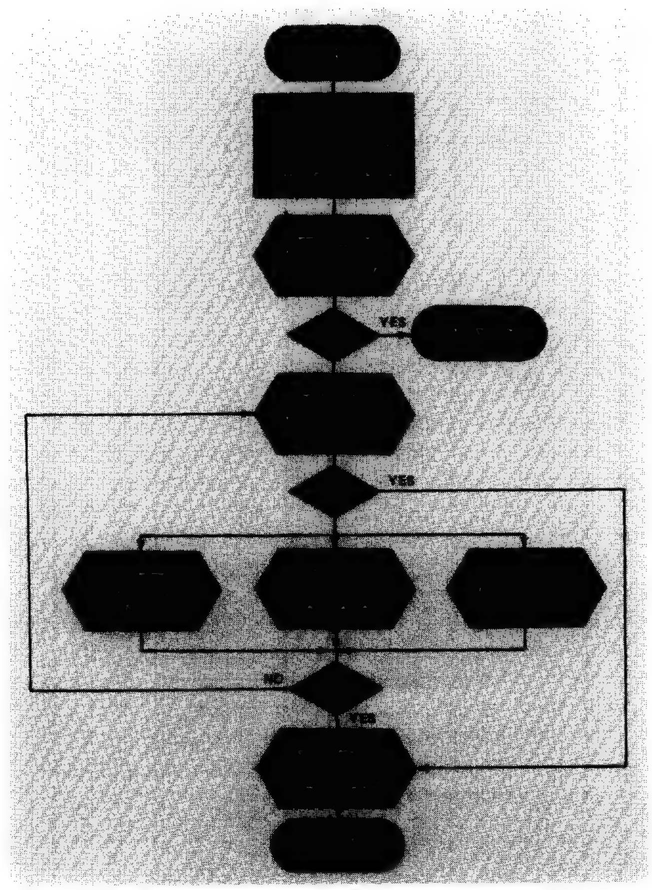

Figure 5

formed and the time when it is recreated. These minimum capabilities have been included in the prototype computer aided inspection system.

Elimination of Film Possible

This project has produced a system that is capable of meeting the inspection requirements for assembly verification of large, complex parts. Real time X-ray will be implemented for inspection of the ROLAND missile propulsion unit. Cost savings of $1.1 million per 10,000 missiles could be realized.

Future efforts should be directed toward expanding the applicability of non-film radiography. Assembly of a real time system with sufficient resolution to inspect castings and welds should be accomplished expeditiously. Another possibile application is evaluation of composites. Further development of non-film X-ray could lead to the elimination of most film based radiography. The potential cost benefits of replacement of film radiography are so significant that development continuation is strongly recommended to achieve this objective.

INDEX BY TOPIC

Note: The following index entries refer to articles and brief status reports appearing in Vol. 6, Nos. 1 thru 4, and Vol. 7, Nos. 1 and 2.

AAH (Advanced Attack Helicopter); Vol. 3, No. 4, p. 40 (Brief 6); Vol. 6, No. 1, p. 24 (BSR; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 27 (BSR)

AAP (Army Ammunition Plants); Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3 p. 9 (BSR)

Absorption; Vol. 7, No. 3 p. 42 (BSR)

Abradable Seals; Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 2, p. 9

Abrasive Machining; Vol. 2, No. 2, p. 13; Vo.. 6, No. 4, p. 6

Acceptance Tests; Vol. 7, No. 2, p. 10; Vol. 7, No. 2, p. 43 (BSR); Vol. 7, No. 2, p. 44 (BSR); Vol. 7, No. 2, p. 48 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 45 (BSR)

Acoustic Microwave Filters; Vol. 6, No. 4, p. 22 (BSR)

Acoustic Testing; Vol. 2, No. 1, p. 32 (BSR); Vol. 2, No. 2

Acoustic Testing; Vol. 6, No. 1 p. 17; Vol. 7, No. 1, p. 16

Actuators; Vol. 7, No. 1, p. 45 (BSR)

Adhesives; Vol. 6, No. 1, p. 17; Vol. 6, No. 3, p. 42

Aerosol Generators; Vol. 7, No. 2, p. 44 (BSR); Vol. 7, No. 2, p. 46 (BSR)

AFM (Abrasive Flow Machining); Vol. 6, No. 4, p. 6

AGT 1500 Recuperator; Vol. 4, No. 1, p. 28; Vol. 6, No. 4, p. 6

AH-1 Cobra Helicopter; Vol. 3, No. 1, p. 14; Vol. 6, No. 4, p. 6

AIDE (automated Image Device Evaluator); Vol. 6, No. 2, p. 24

AIDECS (Automated Inspection Device for Explosive Charge in Shell); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 7 (BSR)

AIME (Automatic In-Process Microcircuit Evaluation); Vol. 6, No. 2, p. 24

Air Velocity; Vol. 7, No. 2, p. 43 (BSR)

Aircraft Engines; Vol. 6, No. 1, p. 40

Airfoils; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2 p. 6 (BSR)

Airframes; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6. No. 2, p. 8 (BSR)

Aluminum; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 28; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 46; Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 3, p. 17; Vol. 7, No. 3, p. 27; Vol. 7, No. 3, p. 43 (BSR)

AMMRC (Army Materials And Mechanics Research Center); Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 26 (BSR);Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 3, p. 9 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 7, No. 1, p. 3; Vol. 7, No. 2, p. 43 (BSR); Vol. 7, No. 2, p. 44 (BSR); Vol. 7, No. 2, p. 46 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 45 (BSR)

Ammunition Manufacturing; Vol. 7, No. 1, p. 16, Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 44 (BSR); Vol. 3, No. 3, p. 8 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 44 (BSR); Vol. 7, No. 3, p. 46 (BSR)

AMTIR-1 Glass; Vol. 6, No. 4, p. 1 (BSR)

AN/ALQ-144; Vol. 6, No. 4, p. 24 (BSR)

AN/TPQ36 Antennas; Vol. 6, No. 4, p. 27 (BSR)

AN/TPQ 37 (Army Firefinder Radar); Vol. 6. No. 4, p. 27 (BSR)

AN/VVS-2D; Vol. 6, No. 4, p. 25 (BSR)

Analytical Methods; Vol. 7, No. 2, p. 44 (BSR)

Anechoic Chambers; Vol. 7, No. 2, p. 31

Antenna Arrays; Vol. 6, No. 4, p. 46; Vol. 7, No. 2, p. 31

Anodizing; Vol. 6, No. 4, p. 21 (BSR)

APPAS (Automatic Process Planning and Selection); Vol. 6, No. 2, p. 32

APS (Arc Plasma Spraying); Vol. 7, No. 3, p. 31; Vol. 7, No. 3, p. 35

APT (Automatically Programmed Tool) System; Vol. 6, No. 2, p. 38

ARBAT (Application of Radar to Ballistic Acceptance Testing of Ammunition); Vol. 7, No. 3, p. 39 (BSR)

Armaments; Vol. 7, No. 2, p. 10

ARMOR; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 28; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 3; Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 42 (BSR), Vol. 7, No. 2, p. 47 (BSR); Vol. 7, No. 2, p. 48 (BSR)

Aromatics; Vol. 7, No. 1, p. 10

ARRADCOM, (U.S. Army Armament Research and Development Command); Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 9; (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 22 (BSR); Vol. 7, No. 1, p. 16; Vol. 7, No. 2, p. 10; Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 44 (BSR); Vol. 7, No. 3, p. 45 (BSR); Vol. 7, No. 3, p 45 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 48 (BSR)

ARRCOM, (U.S. Army Armament Readiness Command); Vol. 7, No. 2, p. 24; Vol. 7, No. 3, p. 17; Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 44 (BSR); Vol. 7, No. 3, p. 45 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR); Vol. 7, No. 3, p. 48 (BSR)
AS/RS (Automated Storage and Retrieval System); Vol. 6, No. 2, p. 38
ATE (Automatic Test Equipment); Vol. 6, No. 3, p. 11
Auger Electron Spectroscopy; Vol. 6, No. 1, p. 17
Ausrolling; Vol. 6, No. 1, p. 23 (BSR)
Autofrettage; Vol. 6, No. 2, p. 13
Automated Inspection; Vol. 6, No. 2, p. 24; Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 4, p. 21 (BSR)(, Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR)
Automated Processing; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 1, p. 28; Vol. 6, No. 2, p. 24; Vol. 6, No. 2, p. 28; Vol. 6, No. 2, p. 38; Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 18; Vol. 6, No. 3, p. 32; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4 p. 25 (BSR); Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR)
Automated Reporting; Vol. 6, No. 4, p. 41
Automated Testing; Vol. 6, No. 2, p. 28; Vol. 6, No. 3, p. 6 (BSR), Vol. 6, No. 3, p. 7 (BSR)
Automated Welding; Vol. 6, No. 3, p. 26; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 28
Automated Wire Bonder; Vol. 7, No. 2, p. 28
AVRADCOM (Army Aviation Research and Development Command); Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 2, p. 9; Vol. 6, No. 3, p. 7 (BSR); Vol. 7, No. 3, p. 8
Aziridines; Vol. 6, No. 3, p. 8 (BSR)

Backspalling; Vol. 7, No. 2, p. 47 (BSR)
Bacteria; Vol. 7, No. 2, p. 43 (BSR)
Ball Bearings; Vol. 6, No. 1, p. 25 (BSR)
Ballistic Tests; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 17; Vol. 6, No. 3, p. 8 (BSR); Vol. 7, No. 1, p. 16; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 43 (BSR); Vol. 7, No. 2, p. 44 (BSR); Vol. 7, No. 2, p. 47 (BSR); Vol. 7, No. 3, p. 39 (BSR)
Battery Cases; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 42 (BSR)
Beam Lead Devices; Vol. 7, No. 3, p. 14
Benite; Vol. 7, No. 3, p. 48 (BSR)
Beryllia; Vol. 7, No. 1, p. 48 (BSR)
Binders; Vol. 6, No. 3, p. 8 (BSR)
Biological Contamination; Vol. 7, No. 2, p. 43 (BSR)
Biological Sensors; Vol. 7, No. 2, p. 44 (BSR); (Vol. 7, No. 3, p. 39 (BSR)
Bit Slice Device; Vol. 7, No. 2, p. 47 (BSR)
Black Hawk Helicopters; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p 27 (BSR)
Black Light TV System; Vol. 6, No. 3, p. 6, (BSR); Vol. 6, No. 4, p. 24 (BSR)
Black Powder; Vol. 7, No. 3, p. 40 (BSR)
Blast Effects; Vol. 7, No. 3, p. 44 (BSR)

BLISKS (integrated Blade and Disk Assembly); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 4, p. 6, Vol. 7, No. 2, p. 47 (BSR)
BLV 63 Bomblets; Vol. 7, No. 3, p. 45 (BSR)
BLV 96B; Vol. 7, No. 3, p. 46 (BSR)
Bonding; Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 3, p. 37; Vol. 6, No. 3, p. 42
Boride Coatings; Vol. 6, No. 2 p. 8 (BSR)
Boron Nitride; Vol. 6, No. 4, p. 24 (BSR); Vol. 7, No. 3 p. 35
Braiding; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 27 (BSR); Vol. 7, No. 1, p. 45 (BSR)
Brazing; Vol. 6, No. 2, p. 6 BSR); Vol. 6, No. 2, p. 9
Breech Components; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 23 (BSR); Vol. 7, No. 3, p. 25
Bridges; Vol. 7, No. 1, p. 45 (BSR)
BTPBS (Base Technology Program Related to Battlefield Systems); Vol. 7, No. 2, p. 3
Burn Rate Test; Vol. 7, No. 2, p. 46 (BSR)
Butyl Rubber; Vol. 6, No. 2 p. 5 (BSR) (BSR)
CAD (Computer-Aided Design); Vol. 6, No. 1, p. 30; Vol. 6, No. 2, p. 3; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 38; Vol. 6, No. 3, p. 32; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, p. 2, No. 41 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 3, p. 46 (BSR)
Cadmium; Vol. 6, No. 4, p. 21 (BSR)
CAF2 TLDS; Vol. 7, No. 2, p. 48 (BSR)
CAI (Computer-Aided Inspection); Vol. 6, No. 2, p. 28; Vol. 6, No. 3, p. 8 (BSR); Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 3, p. 8; Vol. 7, No. 3, p. 47 (BSR)
Calibration; Vol. 6, No. 3, p. 7 (BSR)
CAM (Computer-Aided Manufacturing); Vol. 6, No. 1, p. 34; Vol. 6, No. 2, p. 3; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 32; Vol. 6, No. 2, p. 38; Vol.

6, No. 3, p. 28; Vol. 6, No. 3, p. 32; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 23 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 3, p. 8

CAN-Q Models; Vol. 6, No. 2, p. 32

CAN-Q-COST Computer Program; Vol. 6, No. 2, p. 32

Cannon Tubes; Vol. 6, No. 2, p. 13; Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 9 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 3, p. 25

CAP (Computer-Aided Planning; Vol. 6, No. 2, p. 3; Vol. 7, No. 2, p. 48 (BSR)

Carburizing; Vol. 6, No. 1, p. 23 (BSR)

Cargo Bounce Test; Vol. 7, No. 2, p. 48 (BSR)

Cartridge Cases; Vol. 6, No. 3 p. 6 (BSR); Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 2, p. 2; Vol. 7, No. 3, p. 40 (BSR)

Casting(s); Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 2, p. 44; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 3, p. 46 (BSR)

CAT (Computer-Aided Testing); Vol. 6, No. 2, p. 3; Vol. 6, No. 3, p. 11; Vol. 7, No. 1, p. 16; Vol. 7, No. 2, p. 10; Vol. 7, No. 2, p. 48 (BSR); Vol. 7, No. 2, p. 48 (BSR); Vol. 7, No. 3, p. 45 (BSR)

Cathode Ray Tubes; Vol. 6, No. 4, p. 24 (BSR); Vol. 7, No. 1 p. 47 (BSR

CATLINE Computer Program; Vol. 6, No. 2, p. 32

CAW (Computer-Aided Welding); Vol. 6, No. 1, p. 34

CECOM, (U.S. Army Communication Electronics Command); Vol. 6, No. 4, p. 23 (BSR); Vol. 6, No. 4, p. 24 (BSR)

Center Core Igniters; Vol. 7, No. 3, p 46 (BSR)

Ceramic Materials; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 7, No. 3, p. 14; Vol. 7, No. 3, p. 22; Vol. 7, No. 3, p. 35; Vol. 7, No. 3, p. 45 (BSR)

CFMS (Chain File Mangement System); Vol. 6, No. 4, p. 41

CH-47 Helicopter; Vol. 6, No. 1, p. 3; Vol. 6, No. 4, p. 6

Charcoal Filters; Vol. 7, No. 3, p. 41 (BSR)

Charcoal Tube Tester; Vol. 6, No. 3, p. 7 (BSR)

Chemical Agent Detectors; Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 41 (BSR)

Chemical Analysis; Vol. 7, No. 3, p. 45 (BSR)

Chemical Brazing; Vol. 6, No. 2, p. 9

Chemical Milling; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 2, p. 44

Chemical Vapor Deposition; Vol. 6, No. 4, p. 24 (BSR)

Chromium; Vol. 6, No. 4, p. 21 (BSR), Vol. 7, No. 2, p. 46 (BSR)

CLGP; Vol. 7, No. 1, p. 47 (BSR)

CMOS (Complimentary Metal Oxide Semiconductor); Vol. 7, No. 1, p. 34; Vol. 7, No. 2 p. 28

CMS (Computerized Manufacturing Systems); Vol. 6, No. 2, p. 32

Coal Gasification; Vol. 7, No. 3, p. 43 (BSR)

Coatings; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 28; Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 2, p. 46 (BSR); Vol. 7, No. 3, p. 14

Cobalt; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 2, p. 46 (BSR)

Cocuring; Vol. 6, No. 2, p. 5 (BSR)

COFORM (Coding For Machining); Vol. 6, No. 2, p. 32

Cold Forming; Vol. 7, No. 3, p. 43 (BSR)

Cold Heading; Vol. 7, No. 3, p. 43 (BSR)

Cold Rolling; Vol. 6, No. 1, p. 23 (BSR)

Color; Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 4, p. 26 (BSR)

Combustor Liners; Vol. 6, No. 2, p. 6 (BSR)

Common Module Scanner; Vol. 7, No. 2, p. 43 (BSR)

Communication Systems; Vol. 7, No. 2, p. 47 (BSR)

Composites; Vol. 6, No. 1, p. 7; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 2, p. 18; (Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 3, p. 37; Vol. 6, No. 3, p. 42; Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 2, p. 42 (BSR)

Compressor Blades; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 2, p. 9

Compressor Components; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 2, p. 44

Compressor Discs; Vol. 6, No. 1, p. 40

Computer Interface; Vol.. 7, No. 2, p. 47 (BSR)

Contamination; Vol. 6, No. 1, p. 23 (BSR); Vol. 7, No. 1, p. 45 (BSR)

Coolers; Vol. 6, No. 4, p. 27 (BSR)

Cooling; Vol. 6, No. 2, p. 6 (BSR)

Copper; Vol. 7, No. 1, p. 45 (BSR)

COPPERHEAD System; Vol. 6, No. 2, p. 18; Vol. 6, No. 3, p. 28; Vol. 7, No. 3, p. 39 (BSR)

CORADCOM (Communications R&D Command); Vol. 7, No. 2, p. 28

Corrosion; Vol. 6, No. 4, p. 28

Cost Analysis; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 3, p. 18; Vol. 7, No. 1, p. 3; Vol. 7, No. 1, p. 10; Vol. 7, No. 1, p. 26; Vol. 7, No. 3, p. 17; Vol. 7, No. 3, p. 35; Vol. 7, No. 3, p. 38 (BSR)

Counter Memory Circuits; Vol. 7, No. 3, p. 43 (BSR)

Coxiella Burnetii Slurries; Vol. 7, No. 2, p. 43 (BSR)
CPPP (Computerized Production Process Planning); Vol. 6, No. 3, p. 28; Vol. 7, No. 1, p. 46 (BSR)
Crusher Gages; Vol. 7, No. 2, p. 43 (BSR)
Cryogenic Coolers; Vol. 6, No. 3, p. 6 (BSR)
Crystal Growth; Vol. 6, No. 1, p. 34; Vol. 6, No. 4, p. 26 (BSR)
Crystallography; Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4, p. 27 (BSR)
Curing; Vol. 6, No. 1, p. 7; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 2, p. 8 (BSR)
Cutting; Vol. 7, No. 3, p. 48 (BSR)
Cutting Fluids; Vol. 7, No. 2, p. 47 (BSR)
Cyclotol; Vol. 7, No. 3, p. 38 (BSR)
Cylinders; Vol. 6, No. 2, p. 7 (BSR)

DAAS (Data Acquisition Support System); Vol. 7, No. 2, p. 10
D/PCB (Digital Printed Circuit Boards); Vol. 6, No. 3, p. 11
Defense Industrial Base; Vol. 6, No. 3, p. 3

Degradation; Vol. 6, No. 2, p. 8 (BSR); Vol. 7, No. 1, p. 10; Vol. 7, No. 3, p. 44 (BSR)
Delidding; Vol. 7, No. 1, p. 48 (BSR)
Delineation; Vol. 6, No. 2, P. 5 (BSR)
Detector Arrays; Vol. 6, No. 2 p. 5 (BSR); Vol. 6, No. 4, p. 26 (BSR); Vol. 6, No. 4, p. 46
Detectors; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 4, P. 26 (BSR); Vol. 6, No. 4, p. 46; Vol. 7, No. 1, P. 47 (BSR); Vol. 7, No. 2, p. 31; Vol. 7, No. 3, p. 40 (BSR)
Detonators; Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 9 (BSR)
DFI (Digital Fault Isolation); Vol. 6, No. 3, p. 11
Dielectric Heating; Vol. 6, No. 1, p. 7
Dielectric Materials; Vol. 7, No. 3, p. 31; Vol. 7, No. 3, p. 35
Dies; Vol. 6, No. 1, p. 7; Vol. 6, p. 25 (BSR); Vol. 6, No. 1, p. 40
Diffusion Bonding; Vol. 6, No. 1, p. 25 (BSR)
Diodes; Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 2, p. 48 (BSR); Vol. 7, No. 3, p. 22
Display Switches; Vol. 6, No. 2, p. 6 (BSR)
Dissimilar Joining; Vol. 7, No. 2, p. 41 (BSR)
DMN (Dimethylnitrosamine); Vol. 7, No. 3, p. 44 (BSR)
DMSP Solvent; Vol. 7, No. 3, p. 38 (BSR)
DNBC (Dinitrobenzoyl Chloride); Vol. 6, No. 3, p. 8 (BSR)
DOD (Department of Defense); Vol. 6, No. 1, p. 3
Drive Components; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p.6 (BSR)
Drying Techniques; Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR); Vol. 7, No. 3, p. 48 (BSR)
DTS-70 Automatic Test System; Vol. 6, No. 3, p. 11
Dual Rifling; Vol. 6, No. 2, p. 13; Vol. 6, No. 4, p. 22 (BSR)
Dyes; Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 41 (BSR)

ECAM (Electronics Computer-Aided Manufacturing); Vol. 7, No. 2, p. 41 (BSR)
ECOM, (Army Electronics Command); Vol. 6, No. 4, p. 24 (BSR); Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4, p. 26 (BSR); Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 3, p. 14; Vol. 7, No. 3, p. 31; Vol. 7, No. 3, p. 35

Eddy Current Testing; Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 26; Vol. 7, No. 2, p. 47 (BSR); Vol. 7, No. 3, p. 41 (BSR)
EDM (Electrical Discharge Machining); Vol. 7, No. 3, p. 8
Elastomers; Vol. 6, No. 3, p. 8 (BSR); Vol. 7, No. 1, p. 10
Electro-Optical Systems; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 2, p. 24; Vol. 7, No. 2, p. 42 (BSR)
Electrodeposition; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 21 (BSR)
Electroexplosive Devices; Vol. 7, No. 2, P. 47 (BSR)
Electroluminescent Modules; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 4, p. 23 (BSR)
Electromagnetic Devices; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 2, p. 37
Electromagnetic Radiation; Vol. 7, No. 2, p. 47 (BSR)
Electromechanics; Vol. 7, No. 3, p. 3
Electron Beam Lithography; Vol. 6, No. 4, p. 22 (BSR)
Electronic Devices; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 15; Vol. 6, No. 4, p. 23 (BSR); Vol. 7, No. 1, p. 16; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 24; (Vol. 7, No. 2, p. 46 (BSR); Vol. 7, No. 3, p.3; Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 44 (BSR)
Electropolishing; Vol. 6, No. 3, p. 9 (BSR)
Electrostatic Generation; Vol. 7, No. 2, p. 47 (BSR)
Embrittlement; Vol. 6, No. 4, p. 21 (BSR)
Emission Spectroscopy; Vol. 7, No. 3, p. 45 (BSR)
Encapsulation; Vol. 6, No. 3, p. 18; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 2, p. 37; Vol. 7, No. 3, p. 43 (BSR)
Engineering Steel; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 47 (BSR); Vol. 7, No. 3, p. 17; Vol. 7, No. 3, p. 17; Vol. 7, No. 3, p. 43 (BSR)

Epitaxial Growth; Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4, p. 27 (BSR)
Epoxy Resins; Vol. 7, No. 2, p. 44 (BSR)

ERADCOM (Electronics R&D Command); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 23 (BSR); Vol. 6, No. 4, p. 24 (BSR); Vol. 6, No. 4, p. 25 (BSR); Vol. 6, No. 4, p. 26 (BSR); Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 1, p. 47 (BSR)
Erosion Resistance; Vol. 6, No. 3, p. 9 (BSR)
ESCA (Electron Spectroscopy for Chemical Analysis); Vol. 6, No. 1, p. 17
Etching; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 18; Vol. 6, No. 4, p. 22 (BSR); Vol. 7, No. 1, p. 44 (BSR)
Evaporation Inhibitors; Vol. 6, No. 2, p. 9
Exhaust Emissions; Vol. 7, No. 2, p. 18
Explosive Fill Composition A-7; Vol. 7, No. 3, p. 48 (BSR)
Explosive Fill Composition B; Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 45 (BSR); Vol. 7, No. 3, p. 48 (BSR)
Explosive Fill Composition C-4; Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 46 (BSR)
Explosives; Vol. 6, No. 3, p. 6 (BSR); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 45 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR)
F-100 Engine; Vol. 6, No. 1 p. 40; Vol. 6, No. 2, p. 44
FAD (Forced Air Drying) Process; Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 43 (BSR)
Faraday Cage; Vol. 7, No. 2, p. 47 (BSR)
Fast Burst Reactors; Vol. 7, No. 2, p. 46 (BSR)
Fasteners; Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 3, p. 7 (BSR)
FASTRACE Computer Program; Vol. 6, No. 3, p. 11
Fatigue Tests; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 8 (BSR)
FCC (Flat Conductor Cable); Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15
Feltmetal; Vol. 6, No. 2, p. 9
FFR (Free Flight Rockets); Vol. 7, No. 1, p. 26
FFT (Fast Fourier Transforms); Vol. 7, No. 2, p. 48 (BSR)
Fiber Optic Cables; Vol. 6, No. 4, p. 24 (BSR)
Fiberglass; Vol. 6, No. 2, p. 8 (BSR)
Filament Winding Process; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 3, p. 37; Vol. 6, No. 3, p. 42; Vol. 7, No. 1, p. 45 (BSR)
Filters; Vol. 7, No. 3, p. 22; Vol. 7, No. 3, p. 41 (BSR)
FIREFINDER (Mortar and Artillery Locating Radars); Vol. 6, No. 3, p. 11
Flaw Detection; Vol. 6, No. 3, p. 9 (BSR)
Flexicon Process; Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15
FLIR Sensors; Vol. 7, No. 1, p. 47 (BSR)
Fluidic Amplifiers; Vol. 7, No. 3, p. 43 (BSR)
Flux Core Wire; Vol. 6, No. 3, p. 26
Foams; Vol. 6, No. 1, p. 17
Food Technology; Vol. 7, No. 2, p. 3
Forging(s); Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 3, p. 6 (BSR); Vol. 7, No. 2, p. 18; Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 3; p. 17; Vol. 7, No. 3, p. 27; Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 46 (BSR)
FPW (Flexible Printed Wiring); Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15
Fracture Toughness; Vol. 6, No. 3, p. 9 (BSR)
Friction; Vol. 7, No. 2, p. 45 (BSR)
Fuel Tanks; Vol. 7, No. 2, p. 42 (BSR)
Fuels; Vol. 7, No. 1, p. 10; Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 46 (BSR)
Fungi; Vol. 7, No. 2, p. 43 (BSR)
Fuse Technology; Vol. 7, No. 2, p. 31; Vol. 7, No. 3, p. 3; Vol. 7, No. 3, p. 44 (BSR)
Fuselage Structures; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 8 (BSR)
Gages; Vol. 7, No. 2, p. 43 (BSR)
Gallium Arsenide; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 4, p. 24 (BSR); Vol. 6, No. 4, p. 25 (BSR)
Gallium Arsenide Phosphide; Vol. 6, No. 4, p. 27 (BSR)
Gamma Dosimetry; Vol. 7, No. 2, p. 48 (BSR)
Gas Path Seals; Vol. 6, No. 2, p. 8 (BSR)
Gatorizing; Vol. 6, No. 1, p. 40
Gears; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 3, p. 8 (BSR); Vol. 7, No. 2, p. 41 (BSR)
GENMOD (Computer Program; Vol. 7, No. 3, p. 46 (BSR)
Germanium; Vol. 7, No. 1, p. 47 (BSR)
Gimbals; Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 3, p. 37; Vol. 6, No. 3, p. 42
Glasses; Vol. 6, No. 4, p. 26 (BSR)
Glatt Granulator; Vol. 7, No. 3,. p. 45 (BSR)
Gloves; Vol. 6, No. 2, p. 5 (BSR)
Glycerin; Vol. 6, No. 2, p. 9
Graphite Fibers; Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 3, p. 37; Vol. 6, No. 3, p. 42
Grenades; Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 42 (BSR)
Grinding; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 4, p. 23 (BSR)
Group Technology; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 3, p. 41 (BSR)
Guidance and Control Systems; Vol. 7, No. 1, p. 46 (BSR)
Guided Boring System; Vol. 6, No. 2, p. 13
Gun Barrels; Vol. 6, No. 1, p. 17; Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 4, p. 22 (BSR); Vol.

7, No. 2, . 24; Vol. 7, No. 2, p. 46 (BSR); Vol. 7, No. 3, p. 25
Gyroscope Components; Vol. 7, No. 3, p. 39 (BSR)
HAARS (High Altitude Airdrop Resupply System); Vol. 7, No. 2, p. 3
Handbooks; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 7, No. 1, p. 19
HCC (Hermetic Chip Carrier) Assemblies; Vol. 7, No. 1, p. 34
HDL (Harry Diamond Laboratories); Vol. 6, No. 3, p. 7 (BSR); Vol. 6, No. 4, p. 25 (BSR); Vol. 7, No. 2, p. 31; Vol. 7, No. 3, p. 3; Vol. 7, No. 3, p. 22; Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 45 (BSR)
Heat Pipes; Vol. 6, No. 4, p. 44
Heat Recovery; Vol. 7, No. 3, p. 45 (BSR)
Heat Shields; Vol. 7, No. 1, p. 45 (BSR)
Heat Treating; Vol. 6, No. 1 p. 23 (BSR)
Heating; Vol. 6, No. 1, p. 26 (BSR)
Helicopters; Vol. 6, No. 1, p. 7; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 6 (BSR)
Helicopters; Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 4, p. 6; Vol. 7, No. 2, p. 46 (BSR)
Helmets; Vol. 6, No. 2, p. 5 (BSR); Vol. 7, No. 2, p. 45 (BSR)
HEP (High Explosive Projectiles); Vol. 7, No. 3, p. 39 (BSR)
HERF (High Energy Rate Forging); Vol. 7, No. 3, p. 17
HF1 Projectiles; Vol. 7, No. 3, p. 43 (BSR)
HIP (Hot Isostatic Pressing); Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 44; Vol. 7, No. 3, p. 39 (BSR)
HMX (Cyclotetramethylene Tetranitramine); Vol. 7, No. 3, p. 38 (BSR)
Honeycomb; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 3, p. 9 (BSR)
Hot Forging; Vol. 7, No. 3, p. 39 (BSR)
Housings; Vol. 7, No. 3, p. 40 (BSR)
Howitzers; Vol. 6, No. 2, p. 13; Vol. 6, No. 4, p. 22 (BSR)
HPTN (High Pressure Turbine Nozzle); Vol. 7, No. 3, p. 8
HTPB (Hydroxy Terminated Polybutadiene); Vol. 7, No. 1, p. 26
Hybrid Circuits; Vol. 6, No. 2, p. 24; Vol. 6, No. 4, p. 26 (BSR); Vol. 7, No. 1, p. 34; Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 28; Vol. 7, No. 2, p. 41 (BSR)
IBIS (Integrated Blade Inspection System); Vol. 6, No. 2, p. 6 (BSR)
ICB (Inhibited Chem-Braze System); Vol. 6, No. 2, p. 9
ICPOES (Inductively Coupled Plasma Spectrometer); Vol. 6, No. 1, p. 17
Illuminating Candle Production; Vol. 7, No. 3, p. 42 (BSR)
Impellers; Vol. 7, No. 1, p. 3; Vol. 7, No. 2, p. 47 (BSR)
Impurities Removal; Vol. 6, No. 1, p. 23 (BSR)
Inflow Bleed Test; Vol. 6, No. 3, p. 7 (BSR)
Infrared Components; Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 4, p. 24 (BSR)
Infrared Detectors; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 4, p. 27 (BSR)
Infrared Materials; Vol. 6, No. 4, p. 26 (BSR); Vol. 7, No. 2, p. 43 (BSR)
Infrared Thermography; Vol. 6, No. 1, p. 25 (BSR); Vol. 7, No. 3, p. 8
Injection Molding; Vol. 6, No. 1, p. 17; Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 3, p. 45 (BSR)
Instrumentation Van; Vol. 7, No. 2, p. 48 (BSR)
Insulation; Vol. 6, No. 4, p. 25 (BSR)
Integrated Circuits; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 4, p. 24 (BSR); Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p 44 (BSR); Vol. 7, No. 3, p. 14
Interdigital Filters; Vol. 7, No. 3 p. 22
Interferometry; Vol. 7, No. 2, p. 43 (BSR)
Investment Casting; Vol. 6, No. 2, p. 8 (BSR)
IPDI (Isophorone Diisocyanate); Vol. 7, No. 1, p. 26
IPI (Industrial Productivity Improvement); Vol. 6, No. 4, p. 6
IPS (Inlet Particle Separator); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 6 (BSR)
Isothermal Forging; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 40; Vol. 7, No. 1, p. 3
JAMMER; Vol. 7, No. 3, p. 45 (BSR)
J-Integral; Vol. 6, No. 3, p. 9 (BSR)
Joining; Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 2, p. 6 (BSR)
KAAP (Kansas Army Ammunition Plant); Vol. 6, No. 3, p. 9 (BSR)
Kevlar; Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 7, No. 2, p. 3; Vol. 7, No. 2, P. 41 (BSR); Vol. 7, No. 2, p. 45 (BSR)
Knurl Inspection; Vol. 7, No. 2, p. 44 (BSR)
LACV-30; Vol. 6, No. 2, p. 5 (BSR)
Laminates; Vol. 6, No. 1, p. 7; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 2, p. 18; Vol. 7, No. 1, p. 19; Vol. 7, No. 3, p. 43 (BSR)
LAP Plants (Load, Assemble, and Pack Plants); Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 7 (BSR); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 40 (BSR)
Laser Heating; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 5 (BSR)
Laser Materials; Vol. 6, No. 4, p. 26 (BSR)
Laser Seekers; Vol. 6, No. 2, p. 5

(BSR); Vol. 6, No. 4, p. 26 (BSR)
Laser Welding; Vol. 6, No. 1, p. 28; Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15; Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 45 (BSR)
Lasers; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15; Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 26 (BSR); Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 45 (BSR)
Leak Test; Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 3, p. 6 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 3, p. 41 (BSR)
LED (Light Emitting Diodes); Vol. 6, No. 4, p. 27 (BSR)
Lidar System; Vol. 7, No. 2, p. 46 (BSR)
LIM (Liquid Resin Injection Molding); Vol. 6, No. 3, p. 18; Vol. 6, No. 4, p. 15; Vol. 7, No. 2, p. 37
Liquid Chromatography; Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 2, p. 44 (BSR)
Lithium Chloride Batteries; Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 3, p. 44 (BSR)
Lithium Ferrite; Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 3, p. 31; Vol. 7, No. 3, p. 35
LSH (Large Scale Hybrid) Micro-circuits; Vol. 7, No. 1, p. 34
LTC-712 Engine; Vol. 6, No. 3, p. 7 (BSR)
LTS-101 Engine; Vol. 6, No. 1, p. 26 (BSR)
Lubricants; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 30; Vol. 6, No. 4, p. 21 (BSR)
M-1 Tanks; Vol. 6, No. 1, p. 28; Vol. 6, No. 4, p. 6; Vol. 6, No. 4, p. 28
M-60 Tanks; Vol. 6, No. 3, p. 6 (BSR); Vol. 7, No. 2, p. 44 (BSR)
M100 Electric Detonator; Vol. 6, No. 3, p. 9 (BSR)
M113A1 Armored Personnel Carrier; Vol. 6, No. 4, p. 28
M17A1 Gas Masks; Vol. 7, No. 3, p. 41 (BSR)
M18 Smoke Grenades; Vol. 7, No. 3, p. 41 (BSR)
M201 Howitzers; Vol. 6, No. 2, p. 13; Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 23 (BSR)
M205 Mortars; Vol. 6, No. 4, p. 21 (BSR)
M223 Fuse; Vol. 6, No. 3, p. 9 (BSR); Vol. 7, No. 3, p. 41 (BSR)
M3 Borescope; Vol. 6, No. 3, p. 9 (BSR)
M30 Propellants; Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 47 (BSR)
M42 Grenades; Vol. 7, No. 3, p. 42 (BSR)
M456 Projectiles; Vol. 7, No. 3, p. 43 (BSR)
M46 Grenades; Vol. 7, No. 3, p. 42 (BSR)
M483 Projectiles; Vol. 6, No. 3, p. 6 (BSR); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 46 (BSR)
M549; Vol. 7, No. 2, p. 44 (BSR)
M55 Detonators; Vol. 7, No. 3, p. 38 (BSR)
M68 Cannons; Vol. 6, No. 2, p. 13; Vol. 6, No. 3, p. 9 (BSR); Vol. 6, No. 4, p. 23 (BSR); Vol. 7, No. 2, p. 24; Vol. 7, No. 3, p. 25
M6MP Propellants; Vol. 7, No. 3, p. 47 (BSR)
M735 Fuse; Vol. 6, No. 3, p. 7 (BSR)
M8 Paper; Vol. 7, No. 3, p. 41 (BSR)
M9A1 Gas Masks; Vol. 7, No. 3, p. 41 (BSR)
Machining; Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 2, p. 38; Vol. 6, No. 3, p. 28; Vol. 6, No. 4, p. 6; Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 23 (BSR); Vol. 7, No. 1, p. 3; Vol. 7, No. 2, p. 42 (BSR)
Magnetic Flux Leakage System; (Vol. 6, No. 3, p. 6 (BSR)
Magnetic Materials; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 3, p. 44 (BSR)
Management; Vol. 7, No. 2, p. 41 (BSR)
Mandrel Materials; Vol. 7, No. 1, p. 26
Manufacturing Technology; Vol. 6, No. 1, p. 3; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 1, p. 27 (BSR); Vol. 6, No. 1, p. 30; Vol. 6, No. 2, p. 3; Vol. 6, No. 2, p. 6 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 6, No. 2, p. 13; Vol. 6, No. 3, p. 3; Vol. 6, No. 3, p. 11; Vol. 6, No. 4, p. 6; Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 24 (BSR); Vol. 6, No. 4, p. 33; Vol. 6, No. 4, p. 38; Vol. 7, No. 1, p. 19; Vol. 7, No. 1, p. 34; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 3, p. 4; Vol. 7, No. 3, p. 14; Vol. 7, No. 3, p. 40 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 44 (BSR)
MAP (Manufacturing Analysis Program); Vol. 6, No. 3, p. 32
Maraging Steel; Vol. 7, No. 2, p. 46 (BSR)
Masking; Vol. 7, No. 3, p. 14
Mathematical Models; Vol. 7, No. 3, p. 46 (BSR)
Mechanical Properties; Vol. 6, No. 1, p. 7; Vol. 6, No. 1, p. 14; Vol. 6, No. 1, p. 40; Vol. 6, No. 3, p. 42; Vol. 7, No. 1, p. 3; Vol. 7, No. 1, p. 19
MERADCOM (Army Mobility Equipment Research and Development Command); Vol. 6, No. 3, p. 10 (BSR); Vol. 6 No. 4, p. 27 (BSR); Vol. 7, No. 1, p. 10; Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 3, p. 44 (BSR)
Mercury-Cadmium-Telluride; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 4, p. 26 (BSR)
MET (Manufacturing Engineering Technology); Vol. 6, No. 4, p. 38
Metallization; Vol. 6, No. 4, p. 23 (BSR); Vol. 6, No. 4, p. 25 (BSR)

Metrology; Vol. 6, No. 2, p. 7 (BSR); Vol. 7, No. 2, p. 42 (BSR)
MFMS (Miniature Flexible Manufacturing System); Vol. 6, No. 2, p. 38
MICOM (Army Missile Command); Vol. 6, No. 3, p. 11; Vol. 7, No. 1, p. 19; Vol. 7, No. 1, p. 26; Vol. 7, No. 1, p. 34; Vol. 7, No. 1, p. 44 (BSR); Vol. 7, No. 1, p. 45 (BSR); Vol. 7, No. 1, p 46 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 37; Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 45 (BSR); Vol. 7, No. 3, p. 27
Microcircuits; Vol. 6, No. 2, p. 24; Vol. 6, No. 4, p. 25 (BSR); Vol. 7, No. 1, p. 34; Vol. 7, No. 1, p. 44 (BSR)
Microcomputers; Vol. 7, No. 2, p. 47 (BSR)
Microelectronics; Vol. 6, No. 2, p. 24; Vol. 7, No. 1, p. 44 (BSR)
Microwave Devices; Vol. 6, No. 4, p. 22 (BSR); Vol. 6, No. 4, p. 27 (BSR)
Microwave Energy; Vol. 6, No. 1, p. 24 (BSR)
MIL-C-14460; Vol. 7, No. 2, p. 44 (BSR)
Military Bridges; Vol. 6, No. 2, p. 5 (BSR)
Military Clothing; Vol. 7, No. 2, p. 3; Vol. 7, No. 2, p. 47 (BSR)
Military Footwear; Vol. 7, No. 2. p. 3
Military Personnel Supplies; Vol. 7, No. 2, p. 3
Military Vehicles; Vol. 6, No. 2, p. 5 (BSR); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 8 (BSR); Vol. 7, No. 1, p. 48 (BSR); Vol. 7, No. 2, p. 41 (BSR); Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 43 (BSR); Vol. 7, No. 2, p. 44 (BSR)
Milling; Vol. 6, No. 1, p. 3; Vol. 6, No. 2, p. 38; Vol. 6, No. 4, p. 21 (BSR); Vol. 6, No. 4, p. 22 (BSR); Vol. 7, No. 2, p. 47 (BSR)
Mines; Vol. 7, No. 3, p. 38 (BSR)
Mirrors; Vol. 7, No. 1, p. 47 (BSR); Vol. 7, No. 1, p. 47 (BSR)
Missile Manufacture; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 2, p. 28; Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 2, p. 37; Vol. 7, No. 3, p. 27
MLBs (Multilayer Boards); Vol. 6, No. 2, p. 18; Vol. 7, No. 1, p. 19
MNOS BORAM (Metal Nitride Oxide Semiconductor Block Oriented Random Access Memory); Vol. 6, No. 4, p. 26 (BSR); Vol. 7, No. 3, p. 43 (BSR)
Moire Technique; Vol. 6, No. 3, p. 10 (BSR)
Moisture; Vol. 6, No. 1, p. 17
Molding; Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 3, p. 6 (BSR); Vol. 6, No. 4, p. 15; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 3, p. 40 (BSR)
Molten Salts; Vol. 6, No. 4, p. 27 (BSR); Vol. 7, No. 3, p. 44 (BSR)
Molybdenum; Vol. 6, No. 1, p. 40; Vol. 7, No. 2, p. 46 (BSR)
Mortar Shells; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 2, p 44 (BSR); Vol. 7, No. 3, p. 40 (BSR)
MPBMA (Munitions Production Base Modernization Agency); Vol. 7, No. 3, p. 38 (BSR); Vol. 7, No. 3, p. 39 (BSR); Vol. 7, No. 3 p. 40 (BSR); Vol. 7, No. 3, p. 41 (BSR); Vol. 7, No. 3, p. 42 (BSR); Vol. 7, No. 3, p. 43 (BSR); Vol. 7, No. 3, p. 44 (BSR)p; Vol. 7, No. 3, p. 44 (BSR); Vol. 7, No. 3, p. 45 (BSR); Vol. 7, No. 3, p. 46 (BSR); Vol. 7, No. 3, p. 47 (BSR); Vol. 7, No. 3, p. 48 (BSR);
MRB (Magnetic Borescope Inspection); Vol. 6, No. 3, p. 10 (BSR)
Multilayer Circuits; Vol. 7, No. 1, p. 45 (BSR)
Munitions Technology; Vol. 7, No. 3, p. 44 (BSR)
NARADCOM (U.S. Army Natick R&D Command); Vol. 6, No. 3, p. 8 (BSR)
Naval Weapons Station; Vol. 7, No. 2, p. 41 (BSR)
NC (Nitrocellulose); Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 7, No. 3, p. 48 (BSR)
Near Net Shape Forming; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 40; Vol. 6, No. 2, p. 6 (BSR); Vol. 7, No. 3, p. 27
Nickel; Vol. 6, No. 1, p. 40; Vol. 6, No. 4, p. 6; Vol. 6, No. 4, p. 21 (BSR); Vol. 7, No. 2, p. 46 (BSR)
Nitrate Ester Removal System; Vol. 7, No. 3, p. 42 (BSR)
Nitroguanidine; Vol. 7, No. 3, p. 47 (BSR); Vol. 7, No. 3, p. 48 (BSR)
NLABS (Army Natick R&D Laboratories); Vol. 7, No. 2, p. 3; Vol. 7, No. 2, p. 45 (BSR);
Nondestructive Testing; Vol. 6, No. 1, p. 17; Vol. 6, No. 1, p. 23 (BSR); Vol. 6, No. 1, p. 24 (BSR); Vol. 6, No. 1, p. 25 (BSR); Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 1, p. 40; Vol. 6, No. 2, p. 7 (BSR); Vol. 6, No. 3, p. 6 (BSR); Vol. .6, No. 3, p. 7 (BSR); Vol. 6, No. 3, p. 8 (BSR); Vol. 6, No. 3, p. 9 (BSR); Vol. 6, No. 3, p. 10 (BSR); Vol. 6, No. 3, p. 26; Vol. 7, No. 1, p. 3; Vol. 7, No. 2, p. 24; Vol. 7, No. 2, p. 31; Vol. 7, No. 2, p. 42 (BSR); Vol. 7, No. 2, p. 43 (BSR); Vol. 7, No. 2, p. 47 (BSR); Vol. 7, No. 3, p. 41 (BSR)
Nozzles; Vol. 6, No. 1, p. 26 (BSR); Vol. 6, No. 2, p. 5 (BSR); Vol. 7, No. 1, p. 46 (BSR); Vol. 7, No. 3, p. 8
Nuclear Environment; Vol. 7, No. 2, p. 44 (BSR)
Numerical Controlled Machining; Vol. 6, No. 1, p. 30; Vol. 6, No. 2, p. 32; Vol. 6, No. 2, p. 38; Vol. 6, No. 3, p. 32; Vol. 6, No. 4, p. 23 (BSR)
NVL (Night Vision Lab, Army); Vol. 6, No. 3, p. 6 (BSR)

(To be continued)